Study of energy use and environmental effects in the Garhwal region of the central Himalaya and an action plan for mitigation

Final report
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Contents

PART-I

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PART-II

Summary

II.A Preface

The depletion of forest cover in the Central Himalaya is a known fact. A number of policy initiatives and programmes to improve the forest cover in the region are needed so that the environmental consequences of deforestation are minimized. We undertook a study to examine the environmental consequences of energy use in a well-defined unit to provide a model for similar units elsewhere, with the support of the Ministry of Environment and Forests. Development of an action strategy and implementation of some of the energy management measures further increased the scope of this study.

As can be expected in a study with a large scope, the progress made in different aspects is varied and not always as expected in the original proposal. The estimation of human exposure to pollutants (Total Suspended Particulates and Carbon Monoxide) has provided, for the first time, data to highlight the problem of smoke due to burning of biomass in existing cooking stoves. The problem could get worse in future as people may be forced to use poor quality biomass unless alternative solutions to improve indoor environment are developed and implemented on a large scale. Here, the implementation of stoves with flues has been useful in understanding the need to explore better solutions for improvement of indoor environment.

In understanding the stress on biomass resources due to energy use, an inter-disciplinary approach is developed where the methods used in forestry are applied to estimate woody biomass on all categories of land and the results are combined with the estimated consumption of biomass to meet energy needs in an area. The methodology developed here can be extended to a micro-level planning framework for management of biomass resources. The experiences gained in developing a nursery and plantation provide ideas on local factors to be considered while developing the planning framework.

The data on energy consumption was used extensively for illustrating the use of an optimization model developed as a part of this project. The model has multiple goals and can be refined further to be used as a micro-planning tool.

The success achieved in understanding the impacts of deforestation and in examining the problem of soil erosion is limited and emphasizes a need for a long term focused effort. In the area of development of micro-hydel projects, an approach to identify sites and to prepare detailed feasibility reports is proposed.

It has been our first effort to understand and tackle, to a limited extent, the complex environmental problems in the Himalayan region. We hope to use these experiences in developing better solutions to the problems in the region.

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II.B Abstract

This inter-disciplinary study has enabled us to understand the complexities involved in examining environmental impacts of energy use in a micro-watershed in the Himalayan region. The main aspects of the study were as follows.

1. Examination of energy consumption patterns in three micro-watersheds in Tehri, Pauri and Chamoli districts.
2. Development of a modelling framework to examine the impact of different options on land use pattern.
3. Analysis of stress due to energy use on the woody biomass resources in a few villages.
4. Assessment of human exposures to pollutants (TSP and CO) at different altitudes in different seasons.
5. Preliminary investigations of the impact of deforestation and monitoring of soil erosion.
6. Action strategies included a feasibility study of a micro-hydel site, identification of other sites with micro-hydel potential, implementation of improved cooking stoves, development of a nursery and a plantation, etc.

The analysis of energy use in micro-watersheds in Tehri, Chamoli and Pauri highlighted the close link between energy use and locally available biomass resources. The sustainable yield of woody biomass was estimated in a few villages in each micro-watershed and stress on woody

biomass resources due to energy use was estimated. The stress was found to vary between 2 to 5 for most villages indicating a high degree of degradation. The methodology developed here, needs to be strengthened to identify biomass system boundaries accurately, to cover all type of biomass resources and to incorporate energy and non-energy uses.

Daily integrated exposures to TSP and CO were assessed by personal and stationary sampling of air in six microenvironments. Time budget studies were conducted to determine time spent by four population groups (adult women, children, adult men and youth). Burning of biofuels in traditional unvented cookstoves is the most important source of pollution. The daily exposure of adult women to TSP and CO was the highest and was 36.85 mg h m^{-3} and 110 ppm h respectively. These numbers are high indicating possibility of smoke being an environmental health hazard.

The experiences in the development of action strategies resulted in developing an approach to site selection of micro-hydel projects. The implementation of improved chulhas with flues has highlighted the constraints due to kitchen structures.

II.C Highlights of the findings achieved in the project

The major results obtained from different parts of the study are listed here.

II.C.1 Energy consumption patterns

The sources of energy, for cooking and water heating, in Chamoli and Pauri, were twigs, logs, dung cakes, crop residue and kerosene; whereas in Tehri only firewood logs, twigs and kerosene were used.

There was no seasonal variation in the consumption of kerosene because it was not used for space heating. In Chamoli, there was not much seasonal variation in the consumption of dung cakes and logs. Variation was more marked in the case of twigs which shows that almost the entire increase in consumption of fuel during winter was met by firewood.

The share of twigs in total energy consumption in a village for cooking, water heating and space heating ranged from 85%-100% in Chamoli and from 91%-100% in Tehri. The share of twigs in Pauri was slightly lower because of greater dependence on dung-cakes. It ranged from 79%-85%.

The average time spent daily on cooking ranged between 3 and 6 hours. The traditional mud chulha was used in all three water-sheds. In addition, in some places, kerosene stoves (pressure type) were also used. The percentage of households using kerosene stoves and pressure cookers was

also higher in Chamoli This might explain the higher share of kerosene in total consumption in Chamoli as compared to that in Tehri.

The relationship between altitude and energy consumption was also studied. The relationship between altitude and energy consumption (for cooking, water heating and space heating) in the three watersheds showed an R^2 value for Chamoli = 0.50 which was the highest. Amongst the villages surveyed, Ghimtoli, in Chamoli was situated at the highest altitude (1900 m). The consumption of twigs was the highest in this village. Chopra and Saur Bhatgaon, on the other hand, situated at 910 m and 1025 m respectively, showed the smallest consumption of twigs for cooking and water heating. These were also the only two villages in Chamoli where dung-cakes were burnt for cooking and water heating. The use of dung cakes can probably be attributed to the relatively lower altitude at which these villages are situated or even the higher availability of dung as is the case with village Chopra. In Chamoli, the fraction of fuel burnt specifically for space heating varied from 5.2% to 12.8%. In Pauri it ranged from 0.65% to 5.3% of cooking energy demand.

A majority of the people who were interviewed felt that the problem of fuel-wood scarcity was a very serious one. Many also indicated that over the past few years the number of persons collecting fuel-wood and the number of trips in a day made to the forest had increased. One of

the reasons attributed to this situation was the increasing population pressure. Further, remedial measures to counter the problem as suggested by the people included plantations and fuel substitution.

The quantity of wood carried per trip varied from 23-30 kg in Tehri and 28-36 kg in Chamoli.

Only in two out of the six villages surveyed in Chamoli were dung-cakes made and burnt for cooking and water heating. Dung-cakes were made in all villages in Tehri but in none of the villages were these used as fuel. Instead, they were burnt for driving away mosquitoes.

II.C.2 Modelling framework for land use planning

Six goals are considered in the following order of importance: (1) nutrition level, (2) energy demand, (3) sustainable biomass production, (4) meet energy demand locally, (5) reduce emission and erosion, and (6) grazing area not to drop below 100 ha.

For illustrative purposes, the model was run under five different scenarios as given below:

- Scenario 1 : Business as usual or scenario where the existing land use pattern is considered, i.e., area under forest as 28%.
- Scenario 2 : Forest area to increase by 33% of the total area.
- Scenario 3 : Forest area to increase by 50% of the total area.

Scenario 4 : Forest area to increase by 55% of the total area.

Scenario 5 : Forest area to increase by 66% of the total area.

In none of the scenarios, minimum nutritional demand in terms of food-grains requirement for the people of Shorgad is locally being met. With more and more area under forest, the production of crops decreased. With the present area under forest cover (28% of the total area scenario 1), locally produced food-grain for consumption is 34% less than the supply. The supply-demand gap increases further with greater area under forest. In fact, under scenario 5 the crop production level is zero because of non-availability of cultivable land. Thus, to bring the fraction of area under forest to nearly 2/3rd is not practically feasible proposition for Shorgad.

With an increase in forest area from 28% to 66% there is a marginal decline in the extent of annual soil loss. With 28% forest area, the extent of soil erosion was 0.01% less than the present level of soil erosion. However, when the forest area is taken as 66% the extent of soil loss declined to 17.3% with respect to the present level of soil erosion.

II.C.3 Stress on woody biomass resources due to energy needs

In Chamoli district, village forest land was much less than total agricultural land in all but one village. The total growing stock was observed to be maximum in Ghimtoli village (3295.2 tonnes) whereas Chopra village recorded the minimum (792.5 tonnes). The composition of species revealed that only 3 to 6 species, mostly fodder species, out of the 68 woody species, occupy more than 3 per cent of total basal area. This probably implies that prominent fuel and timber species have already been removed and that now fuel is obtained from shrubs, loppings of timber trees, dead and diseased trees. At times, major species with more than 3 per cent of total basal area contributed only little to woody biomass.

In Tehri district, in the surveyed micro-watershed the highest total growing stock (19995.4 tonnes) was recorded in Daggar village, whereas the lowest (831.87 tonne) was observed in village Siur. The flora here is enriched by 110 woody species, among which 11 species occupy more than 3 per cent of total basal area in different villages. Besides the number of major species, the composition of species also reflects a marked difference with that in Chamoli as 'Paiyan', 'Sal', 'Khinna', 'Genthi' and 'Timla' have a marked presence. Among these species, 'Bheemal' was the only major species which was present on a significantly larger portion of basal area in almost all the villages. The major share of woody biomass, varying

between 56 to 91 per cent, was contributed by miscellaneous species.

The forest communities of Pauri Garhwal extend between dry and moist temperate regions. In the villages in the study area, out of 27 woody species, only 4 species occupy more than 3 per cent of the total basal area. The maximum total growing stock (1158 tonnes) was observed in Bhimalli-malli village, whereas the minimum (916.5 tonnes) was recorded in Bhainswara village.

Stress defined as a ratio of annual consumption of woody biomass as energy to sustainable yield was computed for all the villages, and revealed that generally people consumed 2 to 5 times the sustainable yield from the growing stock within the village boundary. In a few villages stress was more than 10. Our methodology excluded shrubs and bushes as we enumerated only the growing stock which has a girth above 20 cm at breast height.

II.C.4 Human exposure to CO and TSP due to biofuel combustion

The concentrations of TSP and CO measured in this hilly area during cooking sessions are in the same range (TSP: 3-16 mg m^{-3}, CO: 6-51 ppm) as the concentrations measured by others in the Indian plains. Certain studies have been carried out in Nepal which, like Garhwal, is a hilly region. TSP concentrations as measured in our study are comparable to those measured in Nepal (3-9 mg m^{-3}), but the CO concentrations (40-240 ppm in Nepal) measured by us

are less by at least an order of magnitude. Adult women spend some time in the kitchen during non-cooking hours, preparing for later meals or caring for the children. Mean concentration in this micro-environment was found to be significantly high for both TSP and CO. This may be due to poor ventilation, which in turn leads to low air exchange rates.

In the living room and outdoors, CO concentrations were found to be below the detection limit of our instruments. This suggests that CO has its source only in the combustion of biofuels and that CO which escapes the kitchen is quickly diluted. TSP concentrations in the living room were, however, non-zero. This may be due to infiltration of air from the kitchen and outdoors and re-suspension of dust. Indoor concentrations of TSP were higher than outdoor concentrations.

The variation in concentrations due to differences between households was much less than that due to differences within households.

Concentrations of TSP and CO were strongly influenced by the time of the day when the measurements were made. Concentrations measured during mid-day were significantly higher than the evening and morning concentrations.

Seasonal differences were more significant for TSP concentrations than for CO concentrations. The pattern they followed was also different. TSP concentrations in

each micro-environment were highest in winter followed by summer and monsoon. CO concentrations were highest in summer followed by monsoon and winter. The results of this study are inconclusive regarding the effect of altitude on concentrations. Though for TSP concentrations there was a significant effect of altitude, we did not observe a consistent increase or decrease in concentrations with increasing altitude. Several species of fuel-wood are available at any given altitude. There is also a difference in available species at different altitudes. Therefore, an experiment where the type of fuel-wood is controlled may be more successful in determining the effect of altitude.

For all groups of the population, the indoor micro-environments contribute more to the daily integrated exposure than the outdoor micro-environments. While for women it is cooking that contributes most to the daily exposure, for other groups it is the time spent in the living room which contributes the most. The daily exposure of adult women to TSP and CO was estimated to be 36.85 mg h m^{-3} and 110 ppm h respectively.

The daily integrated exposures to TSP and CO follow the same patterns as their respective concentration patterns with respect to season and altitude. In any village, the variation in daily exposure due to individual differences within a group was only a small fraction of the total variance.

A tendency was observed for individuals to overestimate the time spent in cooking. This led to the estimated daily exposure due to cooking to be higher than the measured value by roughly a factor of 1.5.

The improvement in kitchen environments will require better unvented cooking devices with low emissions or changes in the structure of kitchens.

II.D Likely impact of the work on the scientific potential of the country

The work undertaken in this project has the potential to influence future studies in the areas of i) micro-level land use planning for the management of biomass resources, and ii) assessment of human exposure to different pollutants.

The close link between environment, biomass and human subsistence in the hills makes the task of environmentally sound development planning extremely complex. The methodology to analyze the stress on biomass resources and the optimization framework for land use planning developed under this project can be extended further to develop a computer based micro-planning tool. The Natural Resources Database Management Scheme, Department of Science and Technology has already taken interest in this aspect of the study.

The work on assessing exposures to pollutants has has led to a more reliable and appropriate monitoring strategy.

Researchers in other parts of the country can benefit from the experiences we have gained in the design of an exposure assessment programme. A comprehensive database from different parts of the country using a uniform protocol, as suggested by us, will then greatly advance scientific knowledge of the extent of exposure due to biofuel combustion. Simultaneously, if base-line data on health is collected, then together these can provide inputs for the design of large scale epidemiological studies. The work also has implications for the evaluation of stove performance vis-a-vis reduction in exposure.

II.E Likely user agencies for the data and results

1. Department of Non-conventional Energy Sources
2. Hill Development Division, Planning Commission
3. U.P. Hill Development Department
4. District Administration in Tehri, Chamoli and Pauri
5. Central Pollution Control Board
6. Indian Council of Medical Research
7. National Institute of Occupational Health
8. Natural Resources Database Management Scheme, Department of Science and Technology

PART III

III.A Recommendations including remedial measures relevant to the environmental problems studied under the scheme

III.A.1 Biomass resource assessment

The methodology developed in this project for the computation of stress on biomass resources has the potential to be developed into a micro-level planning tool for biomass management. However, in subsequent studies improvements in methodology in the following are recommended:

1. Accurate identification of system boundaries: People use wood resources from a number of sources such as village land, their own land, forest land, etc. So the assessment of woody biomass within the village boundary only, would estimate only part of the actual biomass being harvested in many cases. Hence, prior to biomass assessment in a village, its biomass system boundary should be identified correctly with the help of villagers.
2. To categorize the land within the system boundary, secondary data, from revenue records is not always adequate. Hence, the records would need to be verified and altered for the purpose of study in the field.
3. The potential for estimation of dung and crop residues available were included in the study of energy consumption patterns. It may be better to

include the estimation of these resources along with the estimation of woody biomass resource.

4. The present methodology enumerated only the biomass above a certain defined girth at breast height (say 20 cm). This overlooked shrubs and young trees which were felled on priority because of their easy transportation, early drying and convenience while burning. In subsequent surveys the point of measurement can be brought down to to 50 cm above ground instead of lowest height (137 cm). Quadrate and sampling methods should be applied for the estimation of not only the young crop or under-growth but also for the woody stock standing over conventional forest land. From the secondary data available with the Forest Department, growing stock in terms of volume could not be determined specially at village level, which emphasized the need to deal with forest secondary data more carefully as well as to crosscheck by field inventory.
5. The method of estimation of sustainable yield needs further refinements.
6. The survey of use of biomass resources should cover energy and non-energy users.

III.A.2 Exposure assessment

1. Research needs to be done on pollutants for which existing data is not adequate, e.g. - Respirable Suspended Particulate matter (RSP), Polynucleic Aromatic Hydrocarbons (PAH), Volatile Organic Compounds (VOC), Oxides of Nitrogen (NO_x), etc.

2. Future studies should attempt <u>personal sampling of Carbon Monoxide.</u>

3. Concerted efforts must be made to <u>develop cheaper and easier sampling techniques</u>, since this is a problem largely confined to the developing world. The instruments available currently had been designed and developed for industrial and occupational situations. These might be too sophisticated and not appropriate to the levels of pollutants encountered in rural kitchens. They further demand a lot of infrastructural facilities in the field (such as electricity for charging batteries, large quantities of span gas for calibration, etc.) as well as a high degree of cooperation from the cooks. These are hard to come by in poor rural communities. While designing new techniques it must also be appreciated that the confines of the small kitchen and the cultural habits of the people do place restrictions on the type of instruments and techniques that can be effectively employed.

4. <u>Personal sampling over 24 h would</u> provide the most reliable estimate. There is one drawback to this: In these communities most of the population groups perform heavy labor of some sort. It would therefore be difficult for them to carry around personal samplers, however mini at sized, all day long. Only a few individuals may cooperate satisfactorily.

5. As an alternative to the above point, future studies could attempt more refined and detailed time budget surveys. It would be preferable if investigators made observations and measurements in the field rather than rely on respondents to fill up questionnaires. In very large studies it would be advisable to first get acquainted with the daily and seasonal micro-environment--activity--time' patterns of the region. This would help in designing appropriate pollution monitoring strategies.

6. There is a need for a standard protocol which should be followed by researchers across regions. Only this would lead to meaningful comparisons of data from different regions.

7. Results from our study and those by others indicate that it is both more effective and appropriate to make many repeated (during a day, across seasons, etc.) measurements in a few households rather than make few measurements in many households.

8. More studies are required to establish the effectiveness of improved stoves in reducing exposures. Preferably exposure should be assessed before and after the installation of the improved stove in a household, with at least a time lapse of at least six months.

9. Many villages in this region are moving towards new sources of energy (kerosene, LPG, electricity). There is also a migration of people from villages to towns. The trade-off in risks associated with various sources of energy needs to be examined.

10. It has been found that smoke accumulated in the kitchen or other rooms of the house poses a direct threat to the health of the people. The incidence of Acute Respiratory Infections in children and diseases like chronic bronchitis, asthma, suphysema, lung cancer and corpulmonale in women can be attributed to the fact that women and small children are the ones who spend most of the time in ill-ventilated kitchens. Moreover the fuel used for cooking i.e. biomass emits a lot of smoke when burned. Therefore, intervention studies need to be done but before carrying them out base-line surveys should be done to identify places where intervention is needed most.

11. Exposure assessment is very expensive. Therefore, it becomes all the more necessary to understand the distribution and variability in fuel usage patterns, housing characteristics, weather, climate, socio-cultural factors, health indicators, etc. before designing an exposure measurement program. Many studies have made the mistake of studying these factors while simultaneously assessing exposure. Often, the results have not been conclusive. This could be avoided in the future by first conducting surveys in the field which gather information on the above factors.

III.B List of research paper published/accepted in the research work done under the scheme

1) Saksena S, Prasad R, Pal R C and Joshi V; Assessment of daily exposure to TSP and CO in the Garhwal Himalaya, Presented at the Sub-regional Expert Consultation on Improved Cookstove Development Programme in South Asian Countries, held at Udaipur, January 21-24, 1991.

2) Khazanchi P, Bose R K, Prasad R and Joshi V; Energy data for micro level planning in hills - a case study, Presented at the Seminar on Environmental Protection Through Standards, Bureau of Indian Standards, New Delhi, 1990.

3) Saksena S, Prasad R, Pal R C and Joshi V; Assessment of daily exposure to TSP and CO in the Garhwal Himalayas; Presented at Indoor Air '90, Toronto, July 29-August 3, 1990.

4) Joshi V and Saksena S; Indoor pollution from energy sources; Colloquium on Non-point Sources of Pollution Impact and Mitigation, Organized by the Central Pollution Control Board, November 20, 1989.

5) Sharma A and Joshi V; Stress Due to Domestic Energy Use on Woody Biomass Resources, To be presented at the IGU Seminar on Monitoring Geo-systems, to be held in December 1991.

6) Assessment of Woody Biomass in the Rural Areas of Tehri and Chamoli. Submitted for publication in Biomass.

7) Saksena S, Prasad R, Pal R C and Joshi V; Patterns of Daily Exposure to TSP and CO in the Garhwal Himalaya, Submitted for publication in Atmospheric Environment

8) Bose R K and Joshi V; A Linear Goal Programming Model to Solve Energy-Environment Conflicts for Optimal Land Use Planning in Mountain Watersheds. Submitted for publication in Journal of Environmental Management.

III.C Whether any research fellow associated with the scheme has been awarded Ph.D. etc. or any other higher degree and if so, name of the fellow and the title of the thesis may be given

Nil

PART IV

PROJECT REPORT

Outline of the report

The objectives of this study were -

i) To quantitatively model the flows of energy in a well demarcated region in the Central Himalaya to include the districts of Tehri Garhwal, Pauri Garhwal and Chamoli.

ii) To establish quantitative relationships between energy use and environmental effects.

iii) To choose selected locations in the region of Garhwal and develop model projects that may reverse the exiting trend of environmental degradation.

The study areas were - Irgad micro-watershed in Garhwal, Chandrabhaga micro-watershed in Tehri Garhwal and Shorgad micro-watershed in Chamoli.

The study was conducted in five parts to cover the three objectives mentioned above. Each one of these are reported separately explaining the specific objectives, methodology followed for conducting the study and analyzing the data, highlighting the important results, and recommending further course of investigations/actions. In some parts, we have been able to generate new data, in some others we have been able to propose new approaches.

In Chapter 2, on energy consumption patterns, the results of a survey carried out in the three micro-watershed are presented. In Chapter 3, a modelling framework for land

use planning is proposed and its use is illustrated using the data from Shorgad micro-watershed.

Chapter 4 summarizes our efforts to estimate woody biomass resources in a village community. The development of an approach to use this data to estimate sustainable yield and stress on the sustainable yield due to energy needs provided very useful insight. We have recommended measures to extend this approach further to develop a planning tool for preparing micro-level biomass management plans.

Chapter 5 covers another important problem i.e. human exposure to CO and TSP, whose severity in the hills may be higher due to greater use of biomass fuels under poor ventilation conditions. Here we have not only measured concentrations in kitchens (as was done by past studies) but also looked at other micro-environments and the time spent by people in these micro-environments. The study also examined a few hypothesis, such as that exposures will always be higher in the cooler seasons and will be higher at higher altitudes. Many such beliefs were not found to be statistically valid, but the magnitude of the exposures was high enough for possible adverse impacts on health.

Chapter 6 essentially explains our work in developing an approach to identify micro-hydel sites, in implementing an improved chulha project, and in developing a plantation.

A micro-watershed

Chapter 2

Energy consumption patterns

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Chapter 2

ENERGY CONSUMPTION PATTERNS

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2 Energy consumption patterns

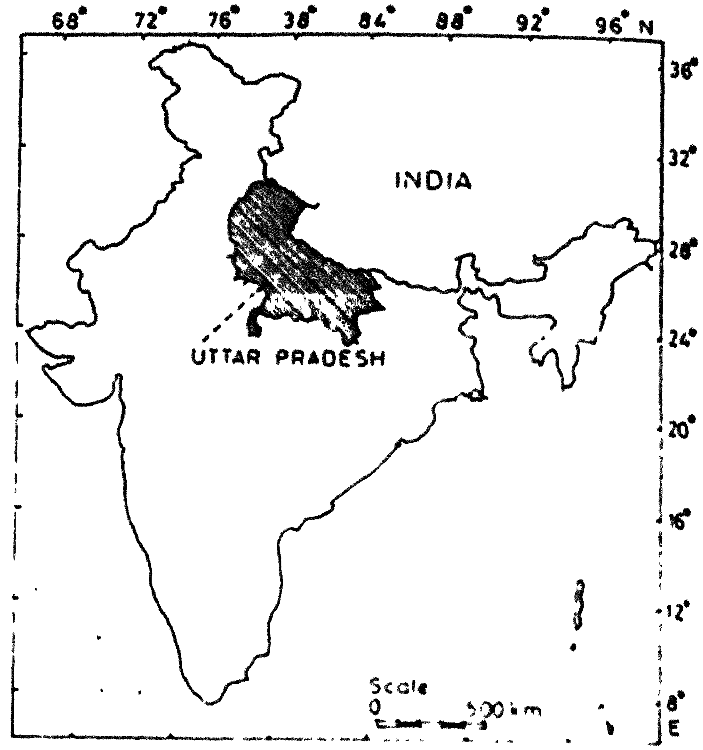
2.1 Objectives

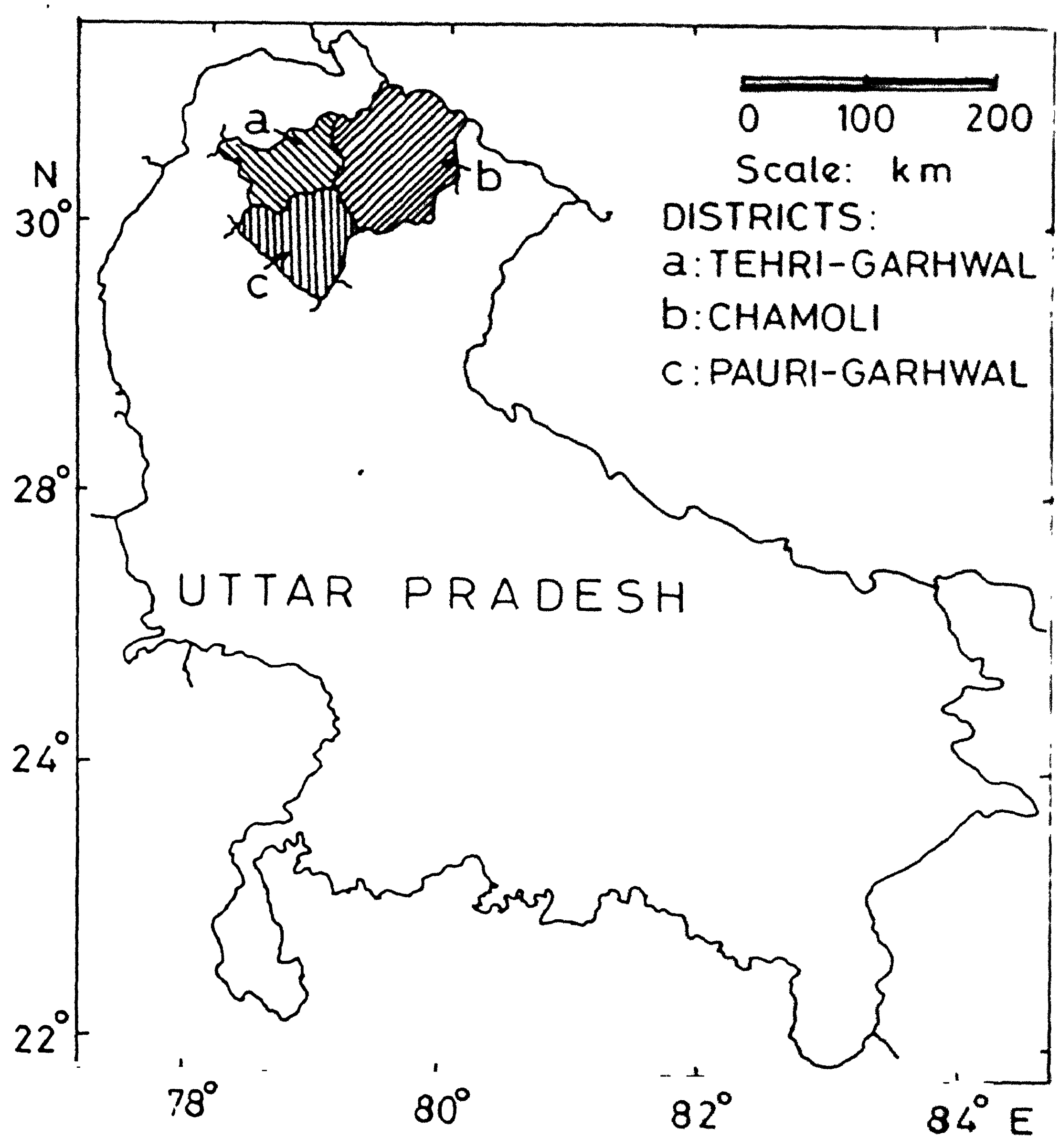
This chapter looks into the pattern of energy consumption in the domestic, agricultural, transport and commercial sectors in the study area. The predominant sources of energy, the use to which they are put and the fuel-mix in each end-use, are all examined in detail. An attempt is made to link energy consumption and the socio-economic and demographic factors characterising these areas. Data on these parameters go as inputs into a model (described in Chapter 3) that is used to arrive at an optimum land-use and fuel-mix pattern. Additionally, on the supply side, availability of biomass resources is determined. Data on annual sustainable yield of woody biomass and consumption levels from the survey are used to arrive at an estimate of stress on woody biomass (see Chapter 4).

2.2 Study area

The Himalayan region in India stretches from Kashmir and Ladakh in the West to Arunachal in the East (Figure 2.1). The Central Himalaya covers an area of about 51,000 km^2 and is located between $28^{o}30'$ and $31^{o}30'$ latitude and 77^{o} and 81^{o} longitude (Kumar and Ahuja, 1987). In the North, they border Tibet while towards the East the border is with Nepal. That part of Himalaya which is in U.P. is divided into Kumaon and Garhwal divisions. Garhwal comprises the districts Chamoli, Uttarkashi, Tehri, Dehradun and Pauri-Garhwal. Kumaon includes Almora, Nainital and Pithoragarh districts.

Fig 2.1 Map of study area





The basic unit chosen for the study is a micro-watershed since it forms the smallest unit of planning in the hills. As also stated in the Seventh Five Year Plan, "more than other elements of nature, water is a dominant arbiter of man and environment in the hills. A geo-hydrological watershed would hence appear to be a better substitute for a development block as a unit of planning" (Government of India, 1985).

Three such watersheds, one in each district, were chosen for the study (Table 2.1). These were in the altitude range of approximately 1000-2000 m, where majority of the villages are located. As a part of trend reversing technologies, a micro-hydel station was to be set up for irrigating a site in Agrora, Irgad watershed, (where a plantation project had been started by the Garhwal University) and also for providing electricity to the nearby villages. A study of the area and its requirements, thus, became essential. The other watersheds chosen were Chandrabagha in Tehri Garhwal, and Shorgad in Chamoli.

2.3 Methodology

2.3.1 Sample

The village survey was carried out in all the villages of the watershed except where the large number of villages was a constraint. The household survey was done in one-third of the villages or a minimum of five whichever was more. The villages were short-listed on the basis of altitude and indices of stress on biomass resources, on

Table 2.1 List of selected villages

District (Watershed)	Altitude (m)	No. of hh	No. of hh surveyed
Pauri (Irgad)			
*Villages			
Agrora	1470	48	12
Dang	1520	90	23
Payasu	1590	42	12
Toli	1330	55	16
Pipli	1350	21	9
Chamoli (Shorgad)			
*Villages			
Ghimtoli	1900	37	20
Kanda	1825	35	20
Kyuri	1650	137	69
Gadil	1300	27	12
S.B. Gaon	1025	128	70
Chopra	910	40	19
Tehri (Chandrabhaga)			
*Villages			
Kasmoli	1200	65	52
Siur	1200	44	36
Guad	1050	19	15
Soni	1050	50	34
Baggar	1225	10	7
Daggar	975	45	32
Talaai	575	35	30

* Villages for the household survey, hh-household

the assumption that both these criteria explain variations in energy demand to a large extent. The three indices of stress are forest land to human population ratio; cultivated land to human population ratio and grazing land to livestock population ratio (Table 2.2 is an example). Villages were stratified according to

altitude range and stress (high, medium and low). The aim was to choose a sample that was representative of the population.

Table 2.2 Stress on land: Chamoli

Village	Cultivated land per person (Nali)	Forest land per person (Nali)	Pasture land per livestock (Nali)
Ghimtoli	8.72 H	7.85 H	30.07 H
Swari Gwas	5.87 H	3.64 M	1.60 L
Kanda	3.17 L	3.10 M	0.46 L
Kyuri	8.50 H	3.32 M	9.26 M
Tarag	4.49 M	5.62 H	2.50 L
Bachhni	4.56 M	3.90 M	1.23 L
Urkholi	2.99 L	5.05 H	4.30 M
Kunda Dankot	5.82 H	6.27 H	0.93 L
Phalasi	5.43 M	2.29 M	0.03 L
Kolhu Bhannu	4.95 M	0.0 L	0.43 L
Gadil	8.17 H	0.0 L	0.26 L
Bhatwari	3.67 L	0.0 L	37.80 H
Chaund	4.27 M	0.39 L	0.0 L
Bora	4.35 M	1.81 L	0.0 L
Bawai	2.22 L	1.33 L	0.07 L
S.B. Gaon	5.16 M	1.65 L	0.66 L
Chopra	2.94 L	0.24 L	2.61 L

H: High, L: Low, M: Medium

Once the choice of villages was made, the households were categorised into large, medium and landless, according to the land ownership pattern. This classification was revised to large, medium and small farmers because the number of landless farmers was extremely small. Large, medium and small farmers were those owning more than 62 nalis (1 acre = 20 nalis), 15 to 60 nalis and less than 15 nalis of land respectively. The procedure for selecting households can be explained with the help of an example.

Suppose the total number of households in the selected villages (say 6) were 1000. Then approximately 20% households from the 6 villages were to be covered. The selection of households belonging to different categories of farmers was done on a proportional basis.

2.3.2 Survey

A questionnaire based survey was carried out at the village and household levels. The survey was done by a group of local personnel who were familiar with the area and its people. A pilot survey was carried out in a few households to pretest the questionnaires which were then suitably modified. The survey was first carried out in Pauri Garhwal. Several gaps in the data collection exercise were noticed both at the time of survey and later when the analysis of data was done. First, data on consumption levels of fuels like dungcakes, fuelwood and crop residue, as reported by the villagers, had to be cross-checked by actual measurements. A spring balance was used to determine the weight of dungcakes and firewood burnt for cooking, water heating and space heating. In Chamoli and Tehri, queries about the quantities of fuel burnt to meet cooking energy demand were supplemented by actual measurement to obtain authentic information. Second, a separate section on fuelwood scarcity to incorporate peoples' perception of fuelwood shortage was added in the questionnaire. Tables 2.3a and 2.3b list the parameters on which data was collected using the

questionnaire. The questionnaires were detailed, incorporating factors influencing end-use energy consumption in the domestic, agricultural, transport and commercial sectors. The complete questionnaire is presented in Appendix 2.1,2.2,2.3,2.4,2.5.

Table 2.3a Information from the village schedule

- Location of the village
- General characteristics: distance from major focal points, altitude, electrification, irrigation.
- Demographic details: number of households, population
- Land particulars: landholding pattern, i.e. the distribution of farmers into 'large' 'medium' and 'small' farmers categories, land use pattern.

Table 2.3b Information from the household schedule

- General: family size, literacy, occupation pattern
- Cooking devices
- Livestock details: number and type of animals, fodder consumption, dung collection.
- Domestic energy consumption across seasons. Consumption of dung, crop residue, firewood, kerosene and electricity for cooking, water heating, space heating and lighting.
- Agricultural energy consumption: crops sown, area covered and irrigated, animate and human energy going into land preparation, weeding, irrigation, harvesting and threshing.
- Collection and preparation of biomass resources: collection of fuelwood, distance travelled for collection, number of dungcakes made by a household, quantity of dung used as manure, construction and plastering.

3.3 Analysis of data

A variety of energy sources are consumed in the domestic sector for different end-uses. For a comparative analysis of energy inputs into an end-use, aggregation was done by first converting the physical quantities of fuels into a common energy unit (**Table 2.4**). These can be converted to useful energy by incorporating efficiencies of devices. Energy consumption for cooking and water heating is dependent to a large extent on the size of the family. To facilitate comparisons, energy consumed was computed on a per capita basis. The energy consumption for space heating or lighting was calculated at the household level because, here, the size of the family is not the determining factor. The annual average consumption for each end-use was computed from seasonal averages, assuming that summer, winter and monsoon each lasts four months. Using these assumptions, energy consumption for different uses was worked out for the villages surveyed.

In the agriculture sector, the energy consumption norms were worked out for the following end-uses : land preparation, weeding, irrigation, harvesting and threshing. Aside from threshing, where the norms were computed on the basis of the weight of grain threshed, in all other activities the norms were calculated on the basis of area cultivated. Energy equivalent for the work done by a adult man is 0.467×10^3 $kcal^{-1}$, whereas for a pair of bullocks it is 2.43×10^3 $kcal^{-1}$ (NCAER, 1979).

Table 2.4 Conversion of original units to calorific value

Energy Source	Unit	kcal/Unit
Dungcake	kg	2130
Firewood twigs	kg	4700
Firewood logs	kg	4750
Crop residue	kg	3500
Kerosene	l	8547

Source: NCAER (1979)

2.4 Analysis of results

2.4.1 Domestic sector

Cooking and water heating

1. Energy use pattern

The main end-uses in the domestic sector were cooking, water heating and space heating. The sources of energy for cooking and water heating in Chamoli and Pauri were twigs, logs, dung cakes, crop residue and kerosene, whereas in Tehri only firewood logs, twigs and kerosene were used. Tables 2.5 and 2.6 give seasonal consumption levels of different fuels used for cooking and water heating in Shorgad and Chandrabhaga. The consumption of logs and twigs in winter was higher than in summer for obvious reasons -- the lower temperature led to increased requirements of wood, not only for cooking and water heating but for space heating as well. There was no seasonal variation in the consumption of kerosene because it was not used for space heating. In Chamoli, there was not much seasonal variation in the consumption of dung cakes and logs. Variation was more marked in the case of twigs which shows that almost the entire increase in consumption of fuel during winter was met by firewood.

Table 2.5 Daily household energy consumption for cooking and water heating: Chamoli

Village	Dung cakes (kg)			Twigs (kg)			Logs (kg)			C.res (kg)	Kerosene (l)		
	S	W	M	S	W	M	S	W	M	W	S	W	M
Ghimtoli	-	-	-	15.2 (100)	23.7 (100)	20.3 (100)	-	-	-	-	1.9 (100)	2.4 (100)	2.6 (100)
Kanda	-	-	-	9.2 (100)	13 (100)	10.8 (100)	-	-	-	-	2.3 (100)	2.3 (100)	2.3 (100)
Kyuri	-	-	-	10 (100)	16.4 (100)	11.7 (100)	12 (1.4)	12 (1.4)	12 (1.4)	-	4.1 (99)	4.7 (99)	4.8 (99)
Gadil	-	-	-	10.1 (100)	13 (100)	10.9 (100)	6 (9)	-	-	2 (8.3)	4.4 (83)	4.8 (83)	5.2 (83)
S.B. Gaon	1.5 (41)	1.7 (57)	2 (7)	7.1 (100)	8.7 (100)	11.3 (100)	6.5 (11.4)	9.1 (12.9)	7.4 (10)	1.9 (40)	3.2 (83)	3.2 (83)	3.3 (83)
Chopra	1.4 (5.2)	2 (5.2)	1.6 (5.2)	9.2 (100)	12.5 (100)	10 (100)	-	-	-	2.2 (58)	3.1 (74)	3.3 (74)	3.5 (74)

S: Summer, W: Winter, M: Monsoon, C.res: Crop residue
Figures in parenthesis denotes the percentage of households using the fuel

Table 2.6 Daily household energy consumption in cooking and water heating: Tehri

Village	Logs (kg)			Twigs (kg)			Kerosene (l)		
	S	W	M	S	W	M	S	W	M
Kasmoli	-	-	-	14.9 (100)	20.7 (100)	15.9 (100)	3 (15.4)	3.3 (15.4)	3.3 (15.4)
Siur	5 (19.4)	7.3 (19.4)	5.7 (19.4)	15.2 (100)	19 (100)	17.1 (100)	3.4 (25)	3.7 (25)	2.6 (55.6)
Guad	-	-	-	15.4 (100)	20.5 (100)	15.5 (100)	0.75 (13.3)	0.75 (13.3)	0.75 (13.3)
Soni	4.8 (17.6)	7.2 (17.6)	5.2 (17.6)	15.2 (100)	[illegible] (100)	13.4 (100)	2.50 (17.6)	3.00 (17.6)	3.30 (17.6)
Baggar	-	-	-	13.1 (100)	17.3 (100)	14.4 (100)	6.30 (42.9)	6.00 (42.8)	8.00 (42.8)
Daggar	2.1 (15.6)	3.8 (15.6)	7.3 (15.6)	14.5 (100)	[illegible] (100)	15.2 (100)	3.40 (53.1)	3.4 (53.1)	3.40 (53.1)
Talaai	4.4 (30)	5 [illegible]	4.3 (30)	13.7 (100)	19.1 (100)	16 (100)	4.20 (40)	4.2 (40)	4.20 (40)

S: Summer, W: Winter, M: Monsoon
Figures in parenthesis denotes the percentage of households using the fuel

This predominant usage of twigs is evident from the consumption pattern in all three watersheds (Figure 2.2). For instance, the share of twigs in total energy consumption in a village for cooking, water heating and space heating ranged from 85%-100% in Chamoli and from 91%-100% in Tehri (Tables 2.7, 2.8). The share of twigs in Pauri (Table 2.9) was slightly lower because of greater dependence on dungcakes. It ranged from 79%-85%.

Table 2.7 Fuel mix for cooking and water heating (%): Chamoli

Village	D.cakes	Twigs	Logs	C.res	Ker
Ghimtoli	-	99.45	-	-	0.55
Kanda	-	99.25	-	-	0.75
Kyuri	-	96.30	1.31	-	2.39
Gadil	-	96.26	1.52	0.38	1.84
S.B.Gaon	2.32	85.38	8.54	1.70	2.07
Chopra	0.43	95.01	-	2.83	1.72

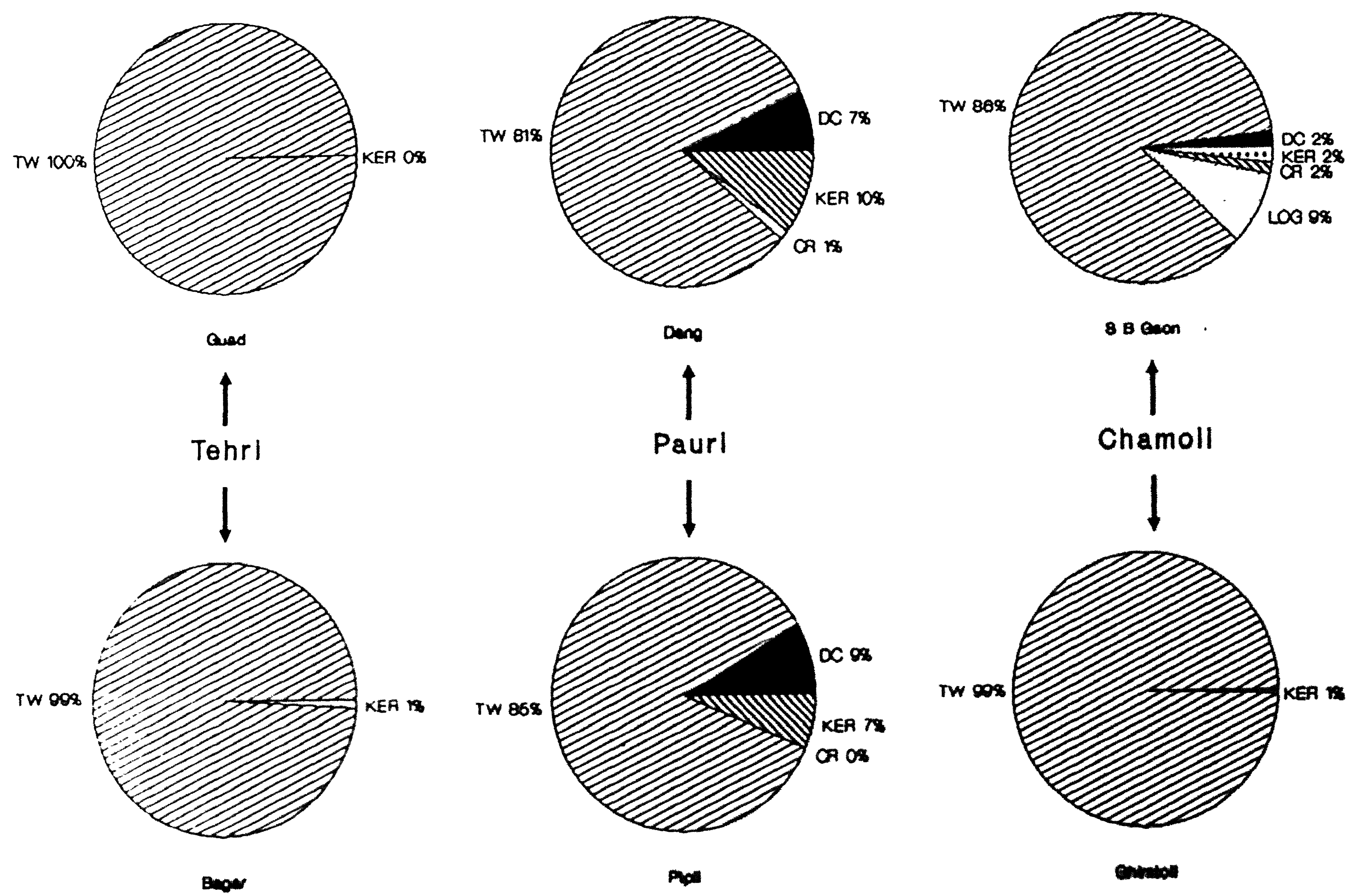
D.cakes: Dung cakes, C.res: Crop residues, Ker: Kerosene

Table 2.8 Fuel mix for cooking, water heating and space heating (%): Tehri

Village	Logs	Twigs	Ker
Kasmoli	-	99.81	0.19
Siur	6.51	93.10	0.39
Guad	-	99.98	0.02
Soni	5.50	94.30	0.20
Baggar	-	98.88	1.12
Daggar	2.74	96.70	0.56
Talaai	8.12	91.28	0.60

Ker: Kerosene

Fig 2.2 Fuel-mix across watersheds



TW:Twigs,KER:Kerosene,DC:Dung cakes,CR:Crop residues

Table 2.9 Fuel mix for cooking, water heating and space heating (%): Pauri

Village	D cakes	Twigs	C.res	Ker
Agrora	7.70	79.10	2.40	10.90
Dang	7.40	81.10	1.20	10.30
Payasu	9.10	79.80	1.20	9.80
Toli	7.01	82.50	0.60	9.80
Pipli	8.60	84.90	-	6.50

D cakes: Dung cakes, C.res: Crop residues, Ker: kerosene

2. Cooking devices

The average time spent daily on cooking ranged between 3 and 6 hours. The traditional mud chulha was used in all three water-sheds. In addition, in some places, kerosene stoves (pressure type) were also used. These were used in 71% and 100% of the villages surveyed in Tehri and Chamoli respectively (**Tables 2.10a and 2.10b**). Moreover, the percentage of households using kerosene stoves and pressure cookers was also higher in Chamoli. This might explain the higher share of kerosene in total consumption in Chamoli is compared to that in Tehri.

Table 2.10a Households using pumpstoves: Tehri

Village	Households using	
	Pumpstoves (%)	Pressure Cooker (%)
Kasmoli	-	21
Siur	0.1	25
Guad	-	-
Soni	21	21
Baggar	43	-
Daggar	22	34
Talaai	33	37

Table 2.10b Households using Pumpstoves : Chamoli

Village	Households using	
	Pumpstoves (%)	Pressure Cooker (%)
Ghimtoli	30	30
Kanda	50	45
Kyuri	58	66
Gadil	58	58
S.B. Gaon	46	50
Chopra	42	37

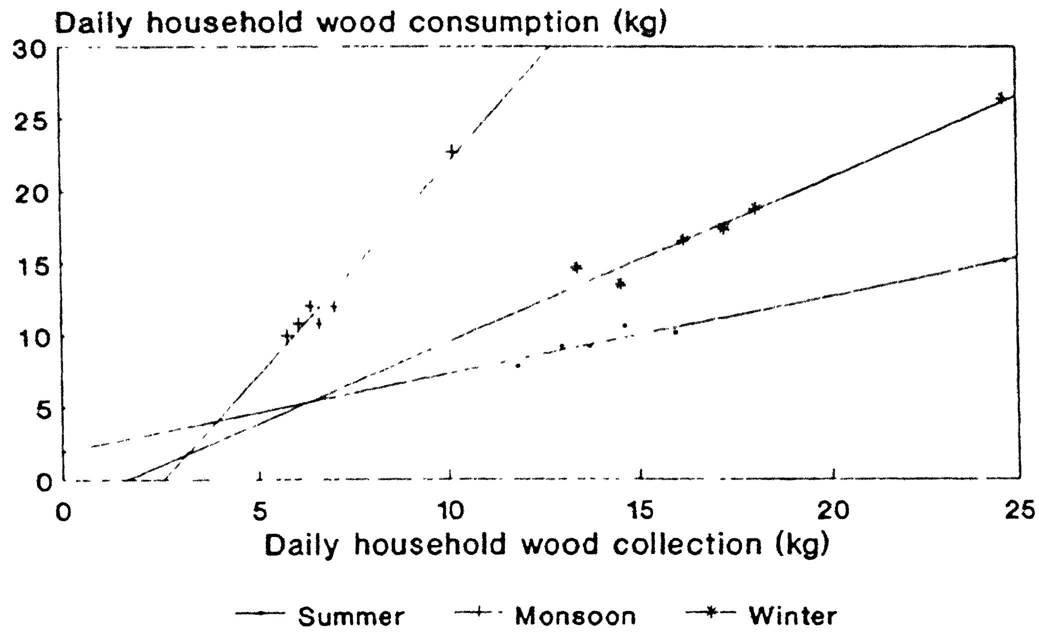
3. Fuel mix

Twigs were burnt in all villages in Tehri, Chamoli and Pauri; logs in 50% of the villages surveyed in Chamoli, in 57% of villages in Tehri and 20% of villages in Pauri; kerosene in 100% of the villages surveyed in Chamoli, Tehri and Pauri, dung cakes everywhere in Pauri, nowhere in Tehri and in just 33% of the villages surveyed in Chamoli. Moreover, the percentage of households using dungcakes was also much larger in Pauri as compared to Chamoli. Crop residue is used in almost every village in Pauri, in none of the villages in Tehri and in half the villages in Chamoli.

Consumption levels of dungcakes showed a large variation across the three watersheds. Daily dungcake consumption for a household ranged from 7-14 kg in summer, 9-13 kg in winter and 2-3 kg in monsoon in Pauri. In Chamoli, it ranged from 0.07-0.62 kg in summer, 0.1-0.9 kg in winter and from 0.08-0.1 kg in monsoon.

The data on consumption and collection of fuelwood showed a positive relation (Figure 2.3). A regression analysis of collection and consumption of fuelwood showed that the value of R^2 was 0.95. The consumption in monsoon was much higher than the collection levels as is evident from the figure. The villagers probably depended on stocks of fuelwood that were available with them.

Fig 2.3 Relationship between consumption & collection of wood:Chamoli



The consumption of twigs in Chamoli and Tehri was comparable. In Chamoli, the consumption for cooking and water heating varied from 7-15 kg for a household during summer, from 9-24 kg in winter and from 11-20 kg in monsoon. The additional amount of fuel burnt specifically for space heating ranged from 2-4 kg for a household. In Tehri, the domestic consumption varied from 13-16 kg in summer, 17-23 kg in winter and 14-19 kg in monsoon. The slightly higher levels in Tehri might be because the data included total fuel burnt for all three activities, namely cooking, water heating and space heating.

The heavy dependence on fuelwood can be explained by a number of factors. Easy accessibility was the most important factor. Crop residue and kerosene were only supplementary sources of energy. Kerosene was used in most of the households in very small quantities, probably just for igniting the logs. Moreover, cooking, water heating and space heating occurred simultaneously and the burning of dung cakes or crop residue did not generate enough heat to keep their houses, of mud and stone, warm.

In Tehri, the use of kerosene stoves was more widespread in Baggar where the share of kerosene in total energy consumption for cooking and water heating was also relatively larger in comparison with the other villages. Again, Kyuri in Chamoli (**Table 2.11a**) reported the highest percentage of households using stoves and the share of kerosene, too, was the highest in this village.

Table 2.11a Land-use pattern (Nali): Chamoli

Village	Village forest	Pasture	Cultivated	Converted barren
Ghimtoli	824.4	2424.3	915.3	1034.4
Kanda	774.8	89.9	792.5	529.8
Kyuri	2323.4	4455.7	5942.6	498.7
Gadil	-	45.8	955.5	115.6
S.B. Gaon	988.1	216.8	3098.5	332.3
Chopra	83.8	410.3	1030.8	172.8

Interestingly, the forest area in Baggar (Table 2.11b) was small and the villagers collected fuelwood from the nearby village forest. In Baggar, not only was the availability of fuel low but the distance of the village from the nearest village forest was also the maximum (Table 2.12a). The nearest forest from Baggar was 3 km away. The average monthly collection of twigs by a household varied from 621-904 kg in summer and from 520-951 kg in winter. The lower limits in both the seasons correspond to the consumption in Baggar. Moreover, a more or less positive relationship was observed between the consumption of kerosene and family income (Table 2.13). Ghimtoli, where family income was the lowest also showed the lowest per capita consumption of kerosene. The opposite held true for Kyuri. The main source of income in these areas was service. The men went out of the village to the cities to earn their living. Agriculture, and in some places, business (from sale of milk and ghee, and small tea-shops) also contributed to family income.

Table 2.11b Land-use pattern (Nali): Tehri

Village	Cultivated	Converted barren
Kasmoli	4387.8	8527.5
Siur	1825.4	3571.8
Guad	1710.3	3460.1
Soni	1264.9	6023.0
Baggar	501.3	1053.0
Daggar	2030.3	3555.8
Talaai	830.2	1155.2

Table 2.12a Distances from major focal points (km): Tehri

Village	Forest	Kerosene Depot
Kasmoli	0.5	4.0
Siur	0.5	1.5
Guad	1.0	1.5
Soni	0.2	1.0
Baggar	3.0	1.5
Daggar	2.0	2.0
Talaai	0.5	0.7

Table 2.12b Distances from major focal points (km): Chamoli

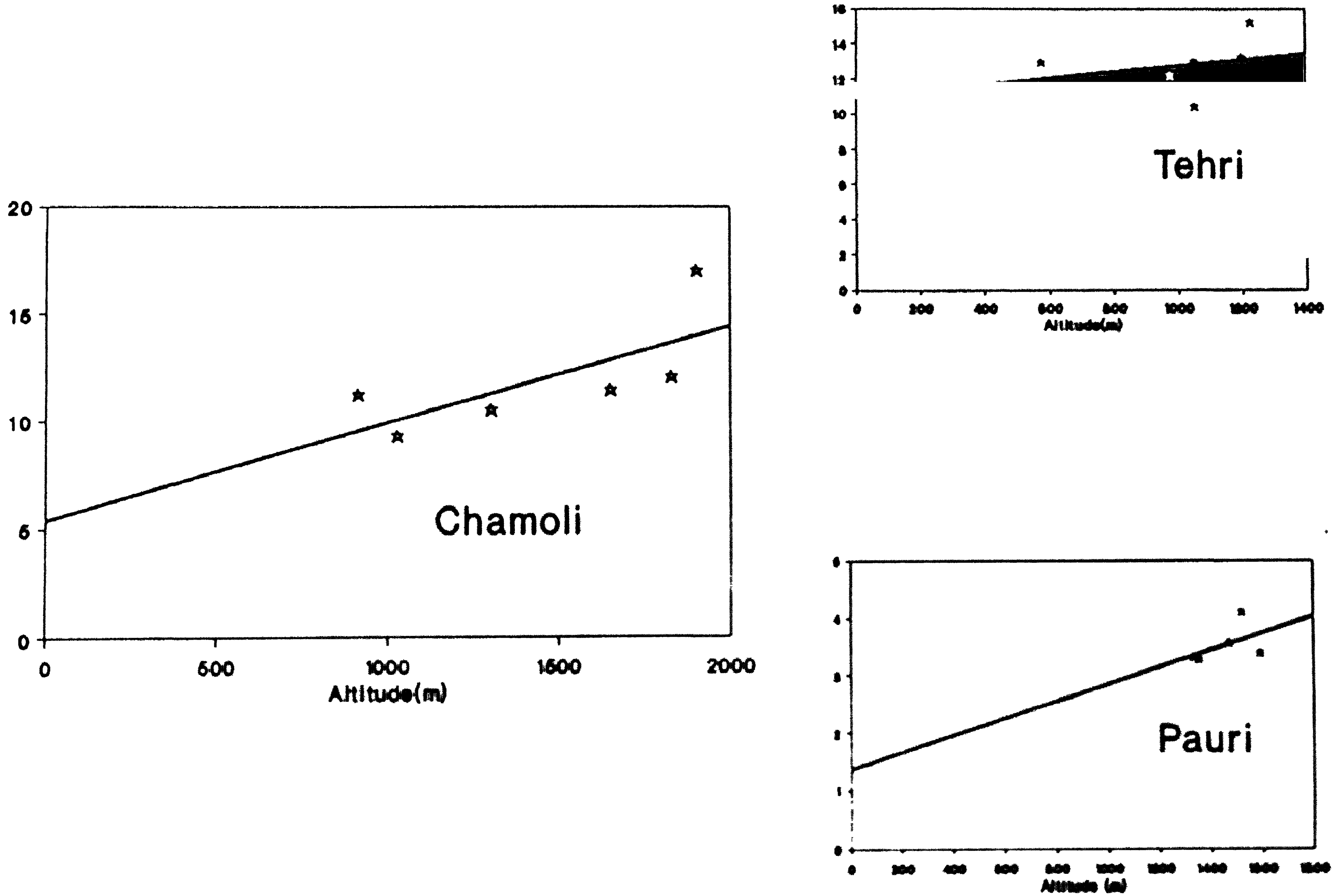
Village	Forest	Kerosene Depot
Ghimtoli	2.0	1.0
Kanda	1.0	1.5
Kyuri	2.0	1.0
Gadil	3.0	1.5
S.B. Gaon	0.5	2.0
Chopra	1.5	4.0

Table 2.13 Household Income profile (Rs): Chamoli

Village	Total monthly income
Ghimtoli	366
Kanda	524
Kyuri	965
Gadil	685
S.B. Gaon	725
Chopra	458

The relationship between altitude and energy consumption was also studied. Figure 2.4 shows the relationship between altitude and energy consumption (for cooking, water heating and space heating) in the three watersheds. The value of R^2 for Chamoli (= 0.50) was the highest. Amongst the villages surveyed, Ghimtoli, in Chamoli was situated at the highest altitude (1900 m). The consumption of twigs was the highest in this village. Chopra and Saur Bhatgaon, on the other hand, situated at 910 m and 1025 m respectively, showed the smallest consumption of twigs for cooking and water heating. These were also the only two villages in Chamoli where dungcakes were burnt for cooking and water heating. The use of dung cakes can probably be attributed to the relatively lower altitude at which these villages are situated or even the higher availability of dung as is the case with village Chopra.

Fig 2.4 Variation of energy consumption with altitude



Vertical axis:Daily per capita energy consumption(million Cal)

Space heating

Data pertaining specifically to space heating was not available in Tehri for the reason that the data on energy consumption for cooking and water heating included that on space heating as well. However, in Chamoli and Pauri, the additional amount of firewood burnt specifically for space heating was also reported (Table 2.14). In Chamoli, the fraction of fuel burnt specifically for space heating varied from 5.2% to 12.8%. In Pauri it ranged from 0.65% to 5.3% of cooking energy demand.

Table 2.14 Daily household energy consumption in space heating (kg): Chamoli

Village	Logs	Twigs	
	W	W	M
Ghimtoli	-	2.7 (100)	2.4 (100)
Kanda	-	1.7 (100)	-
Kyuri	8 (1.4)	2.8 (74.3)	1.1 (10)
Gadil	-	4.4 (100)	-
S.B. Gaon	5.4 (7.1)	3.3 (100)	-
Chopra	-	4.1 (100)	-

W: Winter, M: Monsoon.
Figures in parenthesis indicate percentage of households using the fuel

Lighting

Kerosene and electricity were used for lighting. The percentage of households which used kerosene ranged from 90%-100% in Chamoli and from 73%-100% in Tehri (Tables 2.15 and 2.16) . In Chamoli and Pauri all the villages were electrified unlike Tehri, where five of the

seven villages surveyed were electrified. Also, in Tehri fewer households had electricity connections.

Table 2.15 Monthly household energy consumption in lighting: Chamoli

Village	Kerosene (l)			Electricity (kWh)		
	S	W	M	S	W	M
Ghiatoli	1.4 (100)	1.70 (100)	1.60 (100)	33.50 (10)	38.50 (10)	36.00 (10)
Kanda	1.6 (100)	1.60 (100)	1.60 (100)	30.70 (15)	30.70 (15)	30.70 (15)
Kyuri	1.4 (90)	1.50 (90)	1.40 (90)	34.10 (42.9)	37.20 (42.9)	34.90 (42.9)
Gadil	1.6 (100)	1.70 (100)	1.70 (100)	26.00 (8.3)	26.00 (8.3)	26.00 (8.3)
S.B. gaon	1.1 (100)	1.10 (100)	1.20 (100)	43.60 (25.7)	50.70 (25.7)	44.80 (25.7)
Chopra	2 (100)	2.50 (100)	2 (100)	48.00 (5.3)	48.00 (5.3)	48.00 (5.3)

S: Summer, W: Winter, M: Monsoon
Figures in parenthesis indicates percentage of households using the source of energy

Table 2.16 Monthly household energy consumption in lighting: Tehri

Villages	Kerosene (l)			Electricity (kWh)		
	S	W	M	S	W	M
Kasmoli	2.2 (100)	3 (100)	2.3 (100)	-	-	-
Siur	4.2 (97.2)	4.2 (97.2)	4.2 (97.2)	20.5 (52.8)	20.5 (52.8)	20.5 (52.8)
Guad	1.8 (86.7)	1.9 (86.7)	1.9 (86.7)	14 (73.3)	14 (73.3)	14 (73.3)
Soni	2.5 (94.1)	3.1 (94.1)	2.7 (94.1)	40.5 (58.8)	40.5 (58.8)	40.5 (58.8)
Baggar	2.6 (100)	2.9 (100)	2.6 (100)	-	-	-
Daggar	1.9 (84.3)	2.0 (84.3)	2.1 (84.3)	51 (87.5)	51 (87.5)	50 (87.5)
Talaai	2.1 (73.3)	2.3 (73.3)	2.3 (73.3)	26.4 (83.3)	29.5 (83.3)	27 (83.3)

S: Summer, W: Winter, M: Monsoon
Figures in parenthesis indicates percentage of households using the source of energy

· <u>End-use wise energy consumption</u>

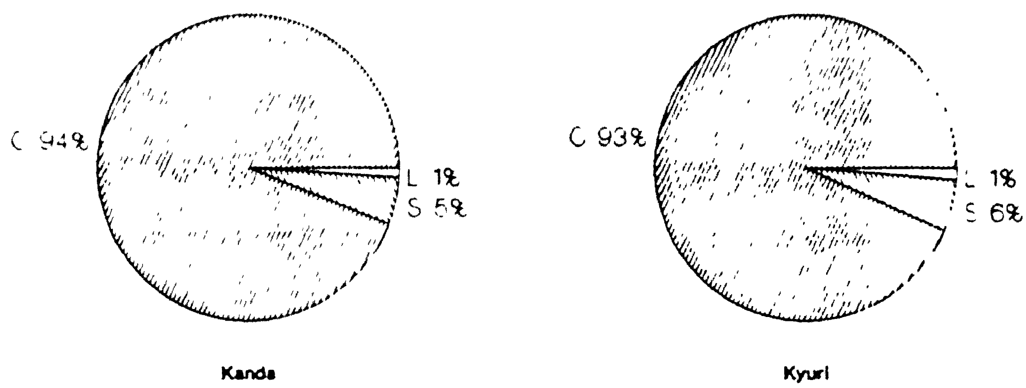
Cooking and water heating account for the largest chunk of energy consumption followed by space heating. Table 2.17 and Figure 2.5 shows this breakup for Chamoli. The share of cooking and water heating in Chamoli ranged from 88-

94%, of space heating from 5%-11% and of lighting from 0-1%. In Pauri, cooking and water heating accounted for 91-97%, space heating for 1-5% and lighting for 1-4% of total energy consumption in the domestic sector.

Table 2.17 Energy consumed in various end-uses (%): Chamoli

Village	Cooking & Water heating	Space heating	Lighting
Ghimtoli	91.51	7.95	0.54
Kanda	94.05	4.93	1.02
Kyuri	93.29	5.52	1.19
Gadil	88.27	10.96	0.78
S.B. Gaon	88.44	10.33	1.22
Chopra	87.66	11.21	1.13

Fig 2.5 End-use wise energy consumption:Chamoli



C.Cooking & Water heating,S.Space heating,L.Lighting

2.4.2 Agricultural sector

All people generally had land to cultivate. Very few were large farmers with above 62 nalis of land (20 nalis = 1 acre). On an average, people generally cultivate 25-30 nalis. One of the major drawbacks here was land fragmentation. Owing to this, land becomes difficult to cultivate and therefore it is left barren. The Rabi season normally extends from October to March and Kharif from June to September. The cropping pattern in the two watersheds did not vary much. Mandwa and Jhangora (Sanwan) form their staple food although they also grow rice and wheat. Other than these, moong, millets, maize and gahat are also grown.

Traditional seeds are used most of the time. Dung is used as manure. Before the monsoon, heaps of dung are scattered in the field and with the first shower it is mixed with ploughing. In Chamoli, people use leaf litter, especially of Banj, along with dung. This litter-dung manure is said to have high levels of NPK nutrients. In Talaai, people even use DAP and urea in the fields.

The irrigated area in Chamoli was very little. It was about 5% of cultivated area as compared to 24% in Tehri Garhwal watershed. Irrigation was primarily through gools (a channel with maximum width of about 18-inches). Gools are generally `kachha'.

The livestock density in Chamoli watershed was also very high, with 296 animals per km^2 as compared to 171 per km^2 in Tehri. Bullocks, which were the primary source of draft power in cultivation, were plenty in Chamoli (24% of total livestock) as compared to Tehri (16% of livestock in Tehri Garhwal). The production of dung by an animal was also higher in Chamoli as compared to Tehri. This may explain the higher crop yield in Chamoli as compared to Tehri (Tables 2.18 and 2.19). Moreover, the Chamoli watershed faces the Himalaya and therefore snow winds reduce water requirements for crops. That explains why the irrigated area in Chamoli was much less. Soil erosion was less and productivity was higher because of well terraced fields.

The main agricultural activities are land preparation, weeding, irrigation, harvesting and threshing. Land preparation and threshing require both human and animal power whereas weeding, irrigation and harvesting use only human power. The percentage share of these activities in total energy consumption showed the predominance in land preparation followed by weeding, harvesting and irrigation in the case of Chamoli. The share of land preparation, in total energy consumption was however, slightly less than of weeding in the case of Tehri Garhwal (Tables 2.20 and 2.21).

Table 2.18 Productivity (kg per Nali): Chamoli

Village	Paddy I	Paddy UI	Mandwa UI	Sanwan UI	Chilli UI	Arhar UI	Gahat UI	Urd UI	Bean UI	Wheat I	Wheat UI	Barley UI	Mustard UI	Masur UI	Maize UI	Maize I	Chaulai UI	Koni UI
S.B. Gaon	63.0	35.6	28.7	33.9	14.4	12.6	12.5	12.9	18.1	16.7	32.2	22.8	21.7	11.0	9.1	-	-	-
Ghiatoli	45.0	35.1	31.4	38.2	-	6.2	4.0	-	12.2	-	-	29.6	28.0	13.2	6.5	15.8	12.1	-
Gadil	57.9	31.3	31.5	31.1	3.8	10.0	9.2	10.5	-	-	37.0	23.9	22.1	8.6	4.3	-	14.1	16.9
Kanda	-	53.4	40.5	52.6	-	10.5	-	-	-	-	28.4	28.7	10.7	-	-	-	-	25.4
Kyuri	52.0	33.8	34.2	35.5	5.5	9.3	5.7	-	10.8	-	-	-	-	-	-	14.6	16.4	-
Chopra	57.8	31.4	26.5	30.3	-	15.2	14.1	14.8	10.3	-	37.5	24.3	23.1	9.5	5.3	-	14.0	17.3

I: Irrigated, UI: Unirrigated

Table 2.19 Productivity (kg per Nali): Tehri

Village	Paddy I	Paddy UI	Mandwa UI	Sanwan UI	Maize I	Maize UI	Arhar UI	Chilli UI	Arbi I	Arbi UI	Gahat UI	Wheat I	Wheat UI	Barley I	Barley UI	Mustard I	Mustard UI	Masur I	Masur UI	Chaulai I	Chaulai UI	Koni I	Koni UI
Guad	-	19.1	22.9	22.8	-	-	-	5.3	-	2.9	4.0	-	15.3	-	21.3	-	8.6	-	3.3	57.5	-	25.7	-
Siur	35.2	19.5	26.6	30.8	-	20.1	-	5.8	-	3.7	-	27.5	15.3	-	12.1	13.0	7.0	4	5.4	-	5.6	-	52.2
Talaai	35.3	-	-	-	15.0	17.5	-	5.1	-	-	-	32.1	-	15.0	21.6	8.5	-	-	10.0	37.5	56.0	50.0	58.75
Caggar	1.9	19.8	22.4	24.5	-	23.1	-	5.5	-	4.9	-	30.3	18.5	-	15.9	-	8.6	-	7.8	-	42.2	-	46.4
Soni	23.1	13.9	23.6	23.6	-	-	-	5.4	3.5	1.2	-	17.8	12.0	-	12.1	-	7.1	-	5.1	-	48.7	-	-
Baggar	20.0	12.5	22.5	17.0	-	32.5	3.0	5.5	-	6.0	-	15.0	10.5	-	9.2	-	5.8	-	4.0	-	75.0	-	-
Kasmoli	22.2	16.3	20.3	21.4	-	35.3	17.6	8.9	-	-	-	-	12.2	-	10.3	-	14.1	-	12.3	-	137.2	-	95.2

I: Irrigated, UI: Unirrigated

Table 2.20 Energy use in agricultural activities (%): Chamoli

Village	Land preparation	Weeding	Irrigation	Harvesting
S.B. Gaon	57.9	26.38	0.85	14.86
Ghimtoli	55.8	44.19	0.01	-
Gadil	56.3	22.30	2.71	18.69
Kanda	74.65	14.67	-	10.68
Kyuri	61.23	23.16	-	15.62
Chopra	69.78	10.88	1.92	17.42

Table 2.21 Energy use in agricultural activities (%): Tehri

Village	Land preparation	Weeding	Irrigation	Harvesting
Guad	39.69	42.28	-	18.03
Siur	33.64	45.96	3.43	16.97
Talaai	50.40	28.26	6.34	15.00
Daggar	39.62	47.00	0.93	12.45
Soni	40.81	41.47	2.27	15.45
Baggar	39.68	47.54	0.71	12.07
Kasmoli	29.83	60.53	0.19	9.46

2.4.3 Transport sector

The length of the road passing through Chandrabagha is 27 km, whereas the road running through Shorgad is just 10 km long. There was a large variation in the number of vehicles plying in the two watersheds (Table 2.22). The diesel consumption by small and big trucks is 0.25 l km^{-1} and 0.35 l km^{-1} respectively.

Table 2.22 Number of vehicles plying daily

Type	Shorgad (Tehri)	Chandrabagha (Chamoli)
Buses	18	150
Big Trucks	20	120
Small Trucks	10	100

2.4.4 Industrial sector

Flour mills are the only industry in this area. A survey was done to assess the energy inputs going into operating these mills. The average monthly electricity bill of a flour mill was Rs 300.

2.4.5 Commercial sector

There are several teashops scattered in the area. These shops depend entirely on firewood as a source of energy. The daily consumption of twigs ranged roughly from 13 kg in summer to 17 kg in winter. The cooking device used was the traditional chulha.

2.5 Biomass resources

2.5.1 Landuse pattern

The land classification in Chamoli was different from that in Tehri Garhwal. In Tehri, land was classified into cultivable land and convertible barren land. The convertible barren land was the source of fuelwood and fodder in Tehri Garhwal. People grow fuelwood/fodder tree species on the land owned by them. Fodder trees, such as 'Bheemal', which need adequate moisture were also grown on the periphery of their agricultural fields. In Chamoli, the land was classified into village forest, pasture land, cultivable land and convertible barren land. With the formation of 'panchayats', people regard these lands as their property and manage them on their own. They protect and maintain these lands. Village forest and pasture land

provided fuelwood and fodder. In Chamoli, the fodder consumption by livestock was higher. Village forest was the major source of fodder. Trees like 'Kharik', growing on their agricultural land also contributed to the fodder availability. With high intake of fodder, the livestock produced more dung in Chamoli. Since dung is not generally used as a fuel in the hills, a large portion of it goes to the agricultural fields.

2.5.2 Woody biomass - perception of fuelwood scarcity

A majority of the people who were interviewed felt that the problem of fuelwood scarcity was a very serious one. Many also indicated that over the past few years the number of persons collecting fuelwood and the number of trips in a day made to the forest had increased. One of the reasons attributed to this situation was the increasing population pressure. Further, remedial measures to counter the problem as suggested by the people included plantations and fuel substitution.

Collection of fuelwood

The quantity of wood carried per trip varied from 23-30 kg in Tehri and 28-36 kg in Chamoli. As can be seen from Tables 2.23a and 2.23b, the collection of wood decreases in monsoon because of the rains. Collection of twigs was higher in Kasmoli where the share of twigs, as a fuel, was also very high. The opposite was true for Chopra and Saur Bhatgaon.

Table 2.23a Collection and preparation of biomass resources: Tehri

Village	Fuelwood collected (kg) per person per trip S	M	W	per month per hh S	M	W	No. D cakes made per hh S
Kasmoli	30	30	29	805	194	951	84
Siur	26	29	25	847	251	578	89
Guad	24	25	24	904	152	665	104
Soni	27	27	27	870	314	710	75
Baggar	21	22	22	621	260	520	80
Daggar	23	23	23	854	210	602	87
Talaai	23	26	23	897	148	626	69

hh: household, D cakes: Dung cakes, S: Summer, M: Monsoon, W: Winter

Table 2.23b Collection and preparation of biomass resources: Chamoli

Village	Fuelwood collected (kg) per person per trip S	M	W	per month per hh S	M	W	No. D cakes made per hh S	M
Ghimtoli	35	33	37	740	305	739	-	-
Kanda	30	28	31	412	198	403	-	-
Kyuri	31	30	31	479	210	542	-	-
Gadil	30	29	29	439	182	518	-	-
S.B. Gaon	29	28	31	355	192	437	80	-
Chopra	29	28	30	390	173	486	67	27

hh: household, D cakes: Dung cakes, S: Summer, M: Monsoon, W: Winter

2.5.3 Dung availability

Tables 2.24a, 2.25a, 2.24b and 2.25b show the average number of livestock owned by a household and the weight of wet dung per animal per day, in Chamoli and Tehri respectively. The average daily dung production by an

animal was more in Chamoli as compared to Tehri. The total dung output for a household was calculated using norms of dung produced and the average number of livestock owned by the household.

Table 2.24a Livestock population (per hh): Chamoli

Village	Cows	Calves	Bullocks	Buffaloes
Ghimtoli	1.31 (65)	1.17 (60)	2.00 (90)	1.27 (75)
Kanda	1.00 (50)	1.42 (60)	1.67 (75)	1.11 (95)
Kyuri	1.34 (59)	1.19 (37)	1.90 (43)	1.28 (66)
Gadil	1.60 (42)	1.86 (58)	1.60 (42)	1.14 (58)
S.B. Gaon	1.43 (53)	1.11 (39)	1.97 (54)	1.21 (60)
Chopra	1.00 (68)	1.22 (97)	2.00 (58)	1.25 (63)

Figures in brackets stand for percentage of households surveyed owning livestock.

Table 2.24b Weight of wet dung produced per animal per day (kg): Chamoli

Village	Cows	Calves	Bullocks	Buffaloes
Ghimtoli	7	2.5	11	17
Kanda	8	3	12	16
Kyuri	8	3.5	10	16
Gadil	8	3	12	18
S.B. Gaon	10	3	12	16
Chopra	10	4	15	20

Table 2.25a Livestock population (per hh): Tehri

Village	Cows	Calves	Bullocks	Buffaloes
Kasmoli	3.67 (12)	2.20 (10)	2.05 (73)	1.73 (98)
Siur	2.00 (22)	1.58 (33)	2.00 (53)	1.53 (100)
Guad	1.33 (40)	1.29 (47)	2.00 (73)	1.36 (93)
Soni	1.68 (56)	1.41 (50)	2.24 (62)	2.03 (91)
Baggar	2.00 (14)	1.75 (57)	2.00 (14)	1.60 (71)
Daggar	1.94 (56)	1.57 (44)	2.21 (59)	1.81 (66)
Talaai	1.56 (53)	1.65 (67)	2.00 (60)	1.56 (77)

Figures in brackets stand for percentage of households surveyed owning livestock.

Table 2.25b Weight of wet dung produced per animal per day (kg): Tehri

Village	Cows	Calves	Bullocks	Buffaloes
Kasmoli	8	2.5	8	12
Siur	8	3	9	14
Guad	9.5	3	9	16
Soni	9	3.5	8	17
Baggar	7.5	2	9	15
Daggar	8	2.5	10	18
Talaai	10	3	8.5	14

The dung output in Chamoli was the highest in village Chopra (Table 2.26) where the consumption of dung cakes for cooking and water heating was also the highest. Dung was used mainly in the fields and in small quantities in households for plastering and construction work. Only in two out of the six villages surveyed in Chamoli were dungcakes made and burnt for cooking and water heating. These villages were Saur Bhatgaon and Chopra. A comparison of dung production and consumption (assuming dung production x 0.2 = Dry dung production and dung consumption x 0.72 is Dry dung consumption) showed that in these two villages only 0.78-6.3% of dung produced was used as fuel (Table 2.27). Surprisingly, dungcakes were made in all villages in Tehri but in none of the villages were these used as fuel. Instead, they were burnt for driving away mosquitoes.

Table 2.26 Daily household dung output (kg): Chamoli

Village	Cows	Calves	Bullocks	Buffaloes	Total
Ghimtoli	5.96	1.76	19.80	16.19	43.71
Kanda	4.00	2.56	15.03	7.99	29.58
Kyuri	6.32	1.54	8.17	13.52	29.55
Gadil	5.38	3.24	8.06	11.90	28.58
S.B. Gaon	7.58	1.30	12.77	11.62	33.27
Chopra	6.80	4.73	17.40	15.75	44.68

Table 2.27 Daily household production and consumption (as fuel) of dung: Chamoli

Village	Production (kg)	Consumption (kg)
Ghimtoli	8.74	-
Kanda	5.92	-
Kyuri	5.91	-
Gadil	5.72	-
S.B. Gaon	6.65	0.42
Chopra	8.94	0.07

2.6 Comparison with other studies

Many surveys have been carried out in the hills. Satsangi and Gautam (1983a and b) covered four village clusters in Nainital District and one village cluster in Agra District in the plains of Uttar Pradesh and studied energy use in various rural activities. Firewood was the single-most important fuel, with 99% share in total energy consumption in the hills cluster, compared to 36% in the plains cluster of villages. The study by Sagar (1981) also showed an increase in the use of dung as fuel, as one moves from the hills towards the plains. The following trends were also observed in our survey and found to be

similar to those observed by others. First, firewood was the predominant fuel. Second, only in the two villages of Chamoli, Chopra and Saur Bhatgaon (situated at low altitude levels), dung cakes were used as a fuel for cooking, although in very small quantities. Pauri was an exception where dung cakes were used extensively. The study by Joshi (1988) on the other hand, pointed out that dungcakes were not used at all in the village clusters of Pauri. However, it is difficult to find an explanation for this discrepancy in observations.

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APPENDIX 2.1 VILLAGE SCHEDULE

VILLAGE NAME ....

BLOCK ....

DISTRICT ....

STATE ....

Project: STUDY OF ENERGY USE AND ENVIRONMENTAL EFFECTS IN THE GARHWAL REGION

OF THE CENTRAL HIMALAYA AND AN ACTION PLAN FOR MITIGATION

Prepared by the:

TATA ENERGY RESEARCH INSTITUTE
7, JOR BAGH, NEW DELHI - 3

Sponsored by the:

MINISTRY OF ENVIRONMENT, FORESTS AND WILDLIFE
GOVERNMENT OF INDIA

OCTOBER 1989

Identification

1. Number of households ...., 2. Altitudinal location (meter): Min: ...., Max: ....,

3. Electrified (1=Yes;0=No) ...., 4. Average family size ...., 5. Total number of school going children ....,

6. Male: Female ...., 7. Total number of households having their own land ...., 8.1 Population, Men(15+) ....,

8.2 Population, Women (15+) ...., 8.3 Population, Children (15-) ...., 9. Distance in km. of the village from the

nearest 9.1 Market ...., 9.2 Tarred road ...., 9.3 Bus stand ...., 9.4 Forest ....,

9.5 Block ...., 9.6 Primary school ...., 9.7 Middle school ...., 9.8 Secondary school ......, 9.9 College ....,

9.10 Dispensary/Hospital ...., 9.11 Bank ...., 9.12 Post Office ...., 9.13 Kerosene depot ....

Land Particulars

a. <u>Present Land Distribution</u> (Pl. report all units in Nali)

1. Cultivable land ...., 2a. Exploitable forest ...., 2b. Reserved forest ....,

3. Pasture land ...., 4. Convertible barren land ....

b. <u>Number of Families of</u>

1. Large farmers (> 60 Nali) ...., 2. Small farmers (< 60 Nali) ...., 3. Landless ....

Water Particulars

a. <u>Source of Water for Irrigation</u> (Y=Yes, N=No)

1. Canal ...., 2. River/Stream/Spring ...., 3. Diesel pumpsets ...., 4. Electric pumpsets ....

5. Others (Pl. specify) ....

b. Source of Water for Drinking and Other Domestic Activities (Y=Yes, N=No)

1. Tap ...., 2. Well ...., 3. River ...., 4. Spring ....,

5.1 How much distance one has to walk to fetch drinking water presently (meters): Min. ...., Max. ....

5.2 How much distance one had to walk to fetch drinking water five years back (meters): Min. ...., Max. ....

c. Hot Water Requirement

1. Number of buckets of hot water required per household per week: Summer ...., Monsoon ...., Winter ...

D. Livestock distribution presently found in the village

Cows	Calves	Bullocks	Buffaloes	Goats	Sheep	Others

E. Crops Grown, Area Sown And Their Productivity

Please report for all the crops which were grown last year in different seasons

	Rabi (From..........To...........)			Kharif (From.........To.........)			Mandwa (From..........To.........)		
Crop Name	Total area sown (nali)	Average yield (qtl/nali)	Price (Rs/quintal)	Total area sown (nali)	Average yield (qtl/nali)	Price (Rs/quintal)	Total area sown (nali)	Average yield (qtl/nali)	Price (Rs/quintal)

F. Energy Source

a. Which of the following direct energy sources do you use in the village (Y=Yes, N=No)

1. Firewood: (logs) ...., 2. Firewood: (twigs/branches) ...., 3. Crop Residue ....,

4. Dungcake ...., 5. Kerosene ...., 6. Diesel ...., 7. Petrol ....,

8. Electricity ...., 9. Coal ...., 10. Soft coke ...., 11. Charcoal ....,

12. Animal power ...., 13. Human power ...., 14. Any other ....

b. Which of the following indirect energy sources do you use in the village (Y=Yes, N=No)

1. Urea ...., 2. DAP ...., 3. Manure ...., 4. Other (Pl. specify) ....

G. Energy Price

Fuel type	Unit	Fuel price	Source distance (km)	Remarks 1=Easily available 2=Difficulty faced
1. Firewood: Logs	Rs/kg			
2. Firewood: Twigs/branches	Rs/kg			
3. Dungcake	Rs/dung cake			
4. Coke	Rs/kg			
5. Kerosene@	Rs/lit			
6. LPG@	Rs/cylinder			
7. Electricity@ (i) Domestic	Rs/kWh			
(ii) Agriculture	"			
(iii) Industries	"			

@ Pl. double check with the district/block officials

I. Technologies

A. <u>Solar Photovoltaic Systems</u> (Lighting) (Y=Yes, N=No)

1. i) Village is electrified Yes/No

ii) Distance from nearest power line ________

iii) Whether village is going to be electrified during the next five years Yes/No

2. i) No. of sunshine hours per day ________

ii) Whether village is covered by shadows for most part of the day Yes/No

3. i) Whether illumination is required for entire village Yes/No

ii) If no, specific place(s) where required (community places) Yes/No

4. i) Local party/person willing to undertake responsibility of maintenance and safety ________

B. <u>SPV System</u> (Water pumping)

1. i) Watertable Summer________ Winter________

2. i) Existing source and means of drinking water

Source		Distance from the village
Boring	________	________
Well	________	________
Stream	________	________
Others	________	________

ii) Present means of water lifting:

Bucket and pulley ________

Handpump ________

Pumpset (diesel) ________

Pumpset (elect) ________

3. If an SPV pump is proposed, does the village have a plot of community land at least 20 x 20 sq.m. in dimensions adjacent to the sources of water and free from any shadow casting structure? Yes/No

C. <u>Hydrams</u>

1) How many streams the village does possess? ....

2) Whether at least one stream has constantly good discharge of water? ....

3) Does the stream have a stretch of at least 25 feet without any meanders?...........

4) Is the land to be irrigated/houses to be supplied nearer to the stream?...........

5) Does the stream have a drop of water flow at one point?...........

APPENDIX 2.2 HOUSEHOLD SCHEDULE

HOUSEHOLD NO --------------

VILLAGE NAME --------------

BLOCK --------------

DISTRICT --------------

STATE --------------

Project : STUDY OF ENERGY USE AND ENVIRONMENTAL EFFECTS IN THE GARHWAL REGION OF THE CENTRAL HIMALAYA AND AN ACTION PLAN FOR MITIGATION

Prepared by the

TATA ENERGY RESEARCH INSTITUTE
7, JOR BAGH, NEW DELHI 110 003

Sponsored by the

MINISTRY OF ENVIRONMENT, FORESTS AND WILDLIFE
GOVERNMENT OF INDIA

October 1989

A. HOUSEHOLD DETAILS

1. Name of the head------------------------, 2. Electrified (Y=Yes, N=No)--------------------,

3. Family Size------, 4. Total person popn. (permanent)-----------, 4.1 Popn. Men (15+)-----------,

4.2 Popn. Women (15+)------, 4.3 Popn. Children (15-)------, 5. Number of school going children------,

6.1 Number of Men (15+) who can read and write-----, 6.2 Number of Women (15+) who can read and write-----,

7.1 Primary occupation---------------------, 7.2 Secondary occupation-----------------,

B. FOOD CONSUMPTION AND COOKING METHODS

1. Average monthly per-household consumption of Rice (Kg.)------, Wheat (Kg.)------, Pulses (Kg.)-------,

2a. Average daily per-household consumption of Milk (Kg.)------------, 2b. Price (Rs./kg) --------------,

3. Do you cook inside your kitchen (Y=yes; N=No)------, 3.1 Number of months cooking inside............,

3.2 Number of months cooking outside......., 4. Number of meals in a day------,

5. Time spent in cooking daily (hrs.)------, 6. Type of utensils used (with type of material)-------------

--------------, ---------------, --------------, 6.1 Do you use a pressure cooker (Y=Yes, N=No) ....

C. Chulhas or Cookstoves Particulars

Chulha			Types of Energy Sources Used	What is the cost of the device	Monthly Energy Expenditure (Rs) Per household
Name	Material	No. of holes			
1.					
2.					
3.					

Q.1. What are the problems faced due to smoke? ....

....

Q.2 How many hours do you use the chulha for cooking in Summer ...., Winter ....

Q.3 How many hours do you use the chulha for water heating in Summer ...., Winter ....

D. LIVESTOCK STATISTICS HOUSEHOLD

Type of animals			Fodder consumed daily per animal				Daily milk production (kg/animal)
	Total No.	Stall-fed	Grazing	Stall-fed (kg/animal	Time spent in Grazing (hours)	Grazing area (acres)	
Cows							
Calves							
Bullocks							
Buffaloes							
Goats							
Sheep							
Others							

Note: (i) Total number of dungcakes made per day .....
*(ii) Average weight of dungcake (kgs.) ....

E. DOMESTIC ENERGY CONSUMPTION

Fuel Type	Unit	Cooking + Water heating S	W	M	Space heating S	W	M	Lighting S	W	M	Total S	W	M
*Dung cake	Nos/day												
*Firewood : logs	Kg/day												
*Firewood : Twigs/branches	Kg/day												
*Crop residue	Kg/day												
Soft Coke	Kg/day												
Kerosene	lit/month												
Electricity	kwh/month												
LPG	cylinders/month												

Note: (i) Weight of 1 LPG Cylinder in kg -----------
* denotes that physical measurements have to be carried out.

Q. What is your monthly Electricity bill for domestic purposes during: a. Summer (Rs.)---------; b. Monsoon (Rs.)----------; c. Winter (Rs.)---------

Q. What is your monthly kerosene consumption during: a. Summer (Rs.)----------; b. Monsoon (Rs.)------------; c. Winter (Rs.)----------------

F. AGRICULTURAL ENERGETICS FOR ONE CYCLE OF CROP PRODUCTION

Please report for the crops you had grown in the last one year in different seasons:

Description	RABI	ZAIB	KHARIF

Crop Particulars

1. Crops grown
   (if mixed cropping Pl.specify)

1.1 HYV/traditional (h/t)

2. Area covered (Nali)

3. Area under irrigation

3.1 Source of irrigation

4. Productivity (Kg./Nali)
   under ·
   (i) irrigated land
   (ii) unirrigated land

Agricultural activities and time spent

5. Land Preparation

a. Draught animal Power

5.1. Type of animal used

5.2. Number of such animals used

5.3. Avg. Time spent/animal pair/day (hrs/day)

5.4. Total number of days used (days)

b. Human Power

5.5. Number of persons engaged

5.6. Avg. Time spent/human day (hrs/day)

5.7. Total number of days used (days)

6. Weeding

6.1. Number of persons engaged

6.2 Avg. Time spent/human day (hrs/day)

6.3. Total number of days used (days)

Description	RABI	ZAID	KHARIF
7. Irrigation			
a. Draught animal Power			
7.1. Type of animal used			
7.2. Number of such animals used			
7.3. Avg. Time spent/animal/day (hrs/day)			
7.4. Total number of days used (days)			
b. Human Power			
7.5. Number of persons engaged			
7.6. Avg. Time spent/human day (hrs/day)			
7.7. Total number of days used (days)			
c. Diesel Pumpset			
7.8. H.P. of the pumpset			
7.9. Average time spent/day (hrs/day)			
7.10 Total number of days used (days)			
7.11 Total diesel consumption (Rs./season)			
d. Electric Pumpset			
7.12 H.P. of the pumpset			
7.13 Average time spent/day (hrs/day)			
7.14 Total number of days used (days)			
7.15 Total electricity consumption (Rs./season)			
8. Harvesting			
a. Human Power			
8.1. Number of persons engaged			
8.2. Avg. Time spent/human day (hrs/day)			
8.3. Total number of days used (days)			

contd/-

Description	RABI	ZAID	KHARIF
9. <u>Threshing</u>			
a. <u>Draught animal power</u>			
9.1 Type of animal used			
9.2 Number of such animals used			
9.3 Avg. Time spent/animal/day (hrs/day)			
9.4 Total number of days used (days)			
b. <u>Human Power</u>			
9.5 Number of persons engaged			
9.6 Avg. Time spent/human day (hrs/day)			
9.7 Total number of days used (days)			
c. <u>Diesel thresher</u>			
9.8 H.P. of the thresher			
9.9 Average time spent/day (hrs/day)			
9.10 Total number of days used (days)			
9.11 Total diesel consumption (Rs./season)			
d. <u>Electric thresher</u>			
9.12 H.P. of the thresher			
9.13 Average time spent/day (hrs/day)			
9.14 Total number of days used (days)			
9.15 Total electricity consumption (Rs./season)			

6. COLLECTION AND PREPARATION OF BIOMASS

6.1 Collection of Wood

Particulars	Summer	Monsoon	Winter
No. of persons collecting			
No. of collection days per week			
No. of trips made by one person in a day			
Total quantity collected per person per trip (kg)			
Distance travelled per trip for collection (km)			
Collection source (type of land)			

6.2 Preparation of Dung

Particulars	Summer	Monsoon	Winter
No. of dungcakes made weekly			
*Average weight of a dry dungcake (kg)			
Quantity of dung used as direct manure (qtl/nali)			
Quantity used for HH use (construction, plastering) (kg)			
Quantity of dung sold (kg)			

H. SCARCITY INDICATORS (Y=Yes, N=No)

1) Do you perceive fuel wood scarcity? YES/NO

2) Does the present firewood consumption vary from the past? YES/NO

2.1) If so, has it increased/decreased? Increased/Decreased

3) Has the no. of persons collecting gone up? YES/NO
By how many?

4) Has the no. of collection trips per week gone up? YES/NO

5) Whether fuel is purchased/collected for special requirements (festivals, marriages?)

6) What do you think are the reasons for fuel scarcity? a..............................

b..............................

c..............................

7) What should be done to reduce scarcity? a..............................

b..............................

c..............................

I. NON-ENERGY REGULAR USES OF BIOMASS

Biomass	Construction	Agricultural Implements	Furniture	Plastering (for dung)	Any export outside the village	Any other
Firewood						
Dung						
Agri Residues						

J. **FAMILY INCOME GENERATED FROM VARIOUS SOURCES**
(To be estimated indirectly)

1. Service (Rs/month)----------- 2. Business (Rs/month)-------------

3. Agriculture (Rs/Rabi Season)------------------------, (Rs/Zaid Season)--------------------------, (Rs/Kharif Season)---

4. Horticulture (Rs/Rabi Season)-----------------------, (Rs/Zaid Season)--------------------------, (Rs/Kharif Season)---

5. Total income (Rs./month) ------------------

6. Total expenditure (Rs./month)

Note: a. Y=Yes, N=No
b. In case of a qualitative response specify in words
c. Indicate 0 if an item is not used and NA if respondents cannot answer

APPENDIX 2.3 COMMERCIAL SCHEDULE

Project: "STUDY OF ENERGY USE AND ENVIRONMENTAL EFFECTS IN THE GARHWAL REGION OF THE CENTRAL HIMALAYA AND AN ACTION PLAN FOR MITIGATION"

Prepared by the
TATA ENERGY RESEARCH INSTITUTE
7, JOR BAGH, NEW DELHI 110 003

Sponsored by the

MINISTRY OF ENVIRONMENT, FORESTS AND WILDLIFE
GOVERNMENT OF INDIA
October 1989+

A. Dhabas/Hotels

1. Energy Consumption Pattern End-use wise

Fuel	Unit	Cooking			Water Heating			Space Heating			
		S	W	M	S	W	M	S	W	M	S
Coke	kgs/month										
Firewood logs	kgs/month										
Twigs	kgs/month										
Kerosene	lts/month										
LPG	cylinders/ month										
Electricity	kWh/month										

2. Plinth area (sq.mts.) ....

3. No.of chairs ....

4. Occupancy ratio (i) Peak season.......... (ii) Off season ....

5. No. of bulbs ....

6. Type of meals cooked ....

7. (i) Type of cooking devices ....

   (ii) Usage (hours per day) ....

APPENDIX 2.4 INDUSTRIES SCHEDULE

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a. Industries

1. Type of Industries Located in the area

Name	Type of products		Total value (Rs/Year)		Output (Ph. Units)	
	Main	By-product	Input	Output	Main	By-product

2. Energy Consumption Pattern in Industries (Rs. spent/month)

End-uses	Coal	Firewood		Kerosene	LPG	Electricity	Diesel
		Logs	Twigs				
Process heat							
Motive power							
Captive power							
Lighting							
Total							

Note: In case break-up is not available, obtain total.

APPENDIX 2.5 TRANSPORT SCHEDULE

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Energy Consumption in Transport

A. Passenger Transport

1. Length of the road passing through the micro-watershed (kms) ____________
2. Number of public buses plying daily, bothways ____________
3. Occupancy ratio in a. Peak season ____________

   b. Off season ____________
4. Diesel consumption per km (litre) ____________
5. Number of trips by each bus one way a. Peak season ____________

   b. Off season ____________
6. Months in a. peak season ____________

   b. Off season ____________
7. Number of seats in the bus ____________

B. Freight Transport

1. Number of big trucks ____________
2. Maximum loading capacity (tonnes) a. Peak season ____________

   b. Off season ____________
3. Number of trips made one way a. Peak season ____________

   b. Off season ____________
4. Number of small trucks ____________
5. Maximum loading capacity (tonnes) a. Peak season ____________

   b. Off season ____________
6. Number of trips one way in a. Peak season ____________

   b. Off season ____________
7. Mileage for small trucks (litres/km) ____________
8. Mileage for big trucks (litres/km) ____________

Chapter 3
Modelling framework for land use planning

Ranjan Kumar Bose
Veena Joshi

Chapter 3

MODELLING FRAMEWORK FOR LAND USE PLANNING

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Modelling framework for land use planning

1 Introduction

It is visually apparent that large areas of the Central Himalaya are being deprived of their forest cover. This implies that the destruction of forests exceeds their natural growth rate. Deforestation has occurred as a consequence of the people's need for fuelwood, fodder, housing materials, agricultural land, etc. The relationships between the change in land use pattern, environment and subsistence economy is not well understood. The demand for fuel and fodder has gone beyond the carrying capacity of the supporting area. Further, as a consequence of deforestation soil erosion occurs. This soil ends up as sediment in streams, causing floods downstream.

In broad terms, an attempt is made to study the environmental consequences of energy use in a well-defined unit. Our objective is to provide a model for studying similar units elsewhere. The Indian Himalaya represents a unique situation, especially in terms of energy availability and consumption pattern. The requirements of energy are high due to the climate and topography of the region. There is a heavy reliance on non-commercial sources of energy, especially firewood, resulting in great pressure on the forests. Moreover, the increasing human and cattle populations have resulted in larger requirements for food, fuel and fodder. Thus, a complex

inter-relationship exists between the areas under cultivation, forest and grazing. People obtain multiple benefits from land but frequently these uses are being competitive. Therefore, instead of limiting our concern to energy use, an attempt is also made to study the environmental implications of energy use.

This chapter deals with the problem of resolving conflicting goals in the management of a micro-watershed. A micro-watershed, named Shorgad (**Figure 3.1**), located in Chamoli district of Central Himalaya was chosen for a case study. The physical features of the micro-watershed are presented in **Appendix 3.1**.

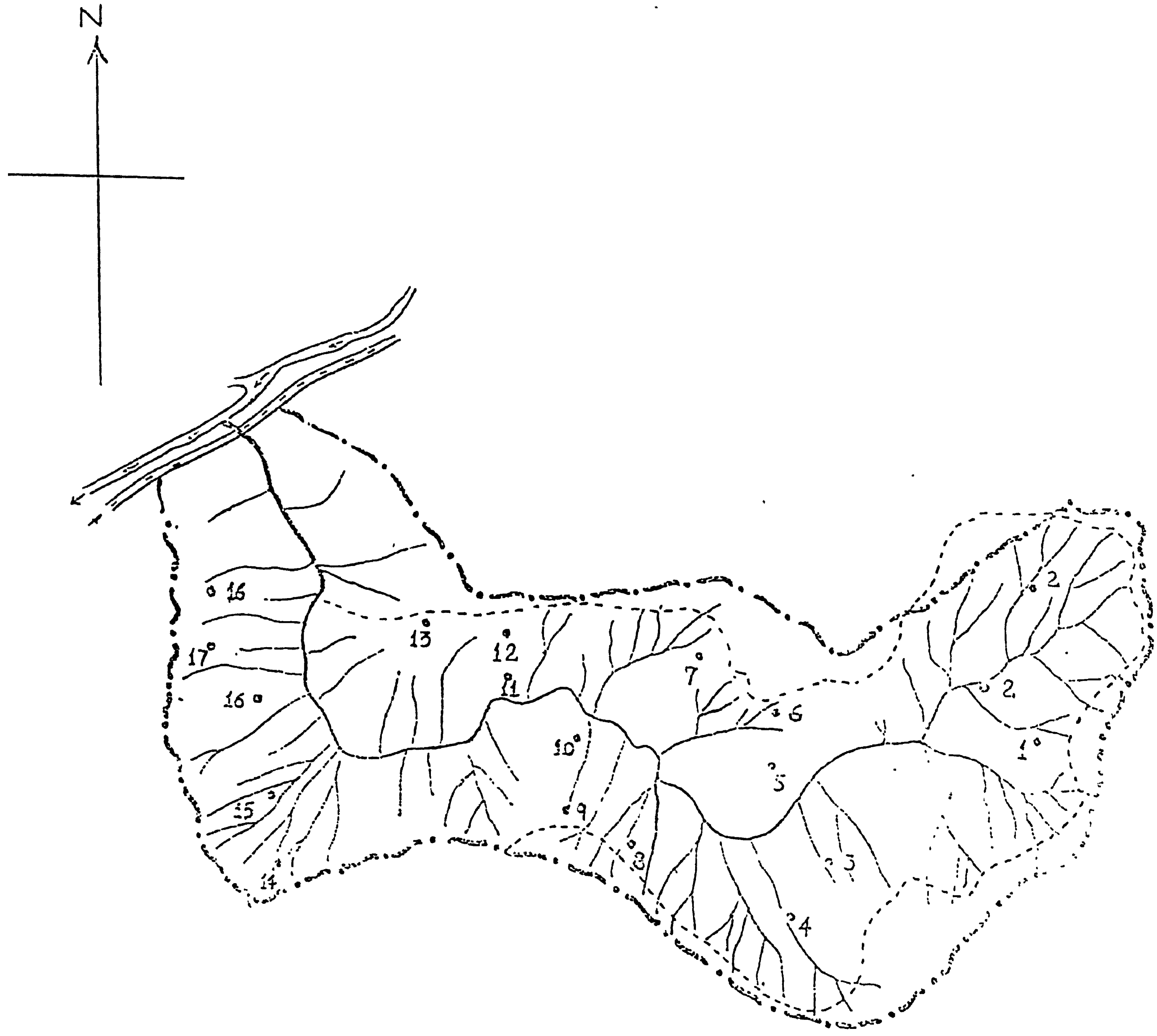
Six goals are considered in the following order of importance:

- G_1 : meet the minimum foodgrain and fodder requirement
- G_2 : meet the present level of energy needs for different end-uses in different sectors
- G_3 : maximize the sustainable production of biomass resources for fuel and/or fodder
- G_4 : estimate the fuel mix to meet the biomass energy requirement
- G_5 : reduce the emission of two pollutants, CO and SPM, which are a consequence of biomass combustion; and also reduce the extent of soil erosion
- G_6 : minimum grazing area -- not to drop below 100 ha

Multiple management goals, especially when the goals conflict, pose a problem which as yet has seldom been satisfactorily resolved. According to van der Zel and Walker (1988), several optimization studies using linear, parametric, quadratic, integer, stochastic and other mathematical programming techniques (D'Aquino, 1974; Bartlett et al, 1974; Cohon and Marks, 1975) have been made; but these techniques are not in common use. In India, no optimization method to cope with the multiple management goals for a watershed is available; and these omissions have hampered the effective management of watersheds in hilly terrain.

Multiple objective programming methods can play a significant role to aid energy-environment planning through the development of integrated land management alternatives. Of the various possible approaches, goal programming is selected as the most appropriate one for our objectives. The relationships in the model are linear and multiple management goals are solved by Linear Goal Programming. The model determines the present pattern of energy use for two sectors - domestic and agriculture. For illustration, five scenarios are considered, where in each scenario the model determines the impact of increase in forest area on the land area under cultivation and pasture area. In addition, the model also determines the optimum mix of energy sources.

Figure 3.1 The Shorgad micro-watershed in Chamoli district of Central Himalaya



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SNo	PARTICULARS	SYMBOL
1	SUB WATERSHED BOUNDARY	
2	REVENUE VILLAGES	
3	STREAM / SPRINGS	

Scale 2 cm = 1 km

3.2 Goal programming

Goal programming (GP) is a powerful multiple objective decision tool and provides a simultaneous solution to a complex system of competing objectives. GP can handle decision problems having single or multiple goals with multiple sub-goals (Lee, 1972). Although it was earlier thought that the technique was first introduced by Charnes and Cooper (1961), but these authors (Charnes and Cooper, 1975) have themselves commented that GP actually originated in the 1950s to obtain 'constrained regression' estimates for an executive compensation problem (Charnes, Cooper and Ferguson, 1955). The GP technique was further developed by Ijiri (1965), Lee (1972, 1973) and Ignizio (1976).

Linear goal programming (LGP) is a modified linear programming technique that views each constraint as a goal or objective to satisfy. The objective function of a LGP consists of deviational variables that take on positive values when goals or objectives cannot be satisfied simultaneously. LGP does not attempt to maximize or minimize the objective criterion directly (as in linear programming). Instead, the deviations between goals and what can be achieved within the given set of constraints are minimized, based on the relative importance or priority assigned to each goal. The deviational variables are represented in two dimensions -- positive and negative deviations from each sub-goal or goal. Prioritizing the deviational variables in the objective function allows for

the conflicting goals to be satisfied, consistent with their ranking of importance to the decision maker. If over-achievement is acceptable, positive deviation from the goal should not be included in the objective function. On the other hand, if under-achievement of a certain goal is acceptable, negative deviation should not be included in the objective function. If the exact achievement of the goal is desired, both negative and positive deviations must be represented in the objective function. GP finds a solution which comes as close as possible to the set goals, satisfying the goals in the order of priority in which they have been given. It also allows the setting of goals in a number of unrelated units (e.g. amount of soil loss in tonnes, land area in hectare, labour input in man days, amount of biogas consumed in kilogram, etc.). In addition, managers can attach ordinal priorities or rankings to the goals in such a way that the relative importance of these is reflected. Mathematically a goal programming can be expressed as follows (Bose, 1990):

$$\text{Minimize } Z = \sum_{h=1}^{H} P_h \left[\sum_{i=n_h}^{m_h} w^-_i d^-_i + \sum_{i=r_n}^{l_h} w^+_i d^+_i \right]$$

Subject to,

$$\sum_{j=1}^{n} a_{ij} x_j + d^-_i - d^+_i = b_i; \qquad i = 1,2,\ldots m$$

$$x_j \geq 0; \qquad j = 1,2,\ldots n$$

$$d^-_i,\ d^+_i \geq 0; \qquad i = 1,2,\ldots m$$

$$w^-_i,\ w^+_i \geq 0 \text{ such that } \sum_{i=n_h}^{m_h} w^-_i + \sum_{i=r_h}^{l_h} w^+_i = 1$$

where, for each $h = 1,2,\ldots\ldots.H$

P_h = Pre-emptive priority factor assigned to goal deviations d^-_i $(i = n_h, n_{h+1}, \ldots m_h)$ and d^+_i $(i = r_h, r_{h+1}, \ldots l_h)$;

w^-_i and w^+_i = Numerical weights assigned to the deviations of goal i at a given priority level;

d^-_i and d^+_i = Negative and positive deviations of goal i;

x_j = Decision variables; $j = 1,2, \ldots n$;

a_{ij} = Technological coefficient of x_j in goal i;

b_i = Value of goal i

In the above model we can also have rigid constraints as given below within a given decision environment.

$$\sum_{j=1}^{n} b_{ij}x_j = C_i; \qquad i = 1,2,\ldots p$$

In this model, all the goals have been grouped into H priority levels and h^{th} priority is assigned to all sub-goals corresponding to under-utilization deviation variables d^-_i $(i = n_h, n_{h+1}, \ldots m_h)$ and over-utilization deviation variables d^+_i $(i = r_h, r_{h+1}, \ldots l_h)$.

Once the possible goals, decision variables, constraints, priorities and weights have been assigned, the model proceeds to find the best solution, by first satisfying the constraints, then the goal priorities, then the goals and finally it expresses this solution in weighted figures. For example, if the primary goal was meeting the basic foodgrain and fodder requirement, the model would first test all decision variables against the constraints for this goal and then minimize the corresponding goal deviation. It would then take the secondary goal (e.g. meeting the present level of sectoral end-use energy demand) and test for each decision variable, already chosen in its set for the first goal, against others that would also improve the secondary goal.

3.3 The mathematical model

The mathematical structure of the LGP model is formulated by analysing the Reference Energy System (RES) for the Chamoli watershed during 1990 (see **Figure 3.2**) by considering the following indices, decision variables, parameters and aspiration levels.

3.3.1 Indices

The following indices take different values and are defined in **Table 3.1** : i = energy source, j = end-use, k = end-use device, p = pollutant, a = animal, c = crop, l = land type and s = sector. From **Figure 3.2** and **Table 3.1** we also define:

G = set of feasible combinations of i, k and j where i = 1,2,..7; k = 1,2,..7 and j = 1,2,...8

$G^{(i)}$ = set of feasible combinations (i,k,j) for fixed energy source i, where k = 1,2,...7 and j = 1,2,..8

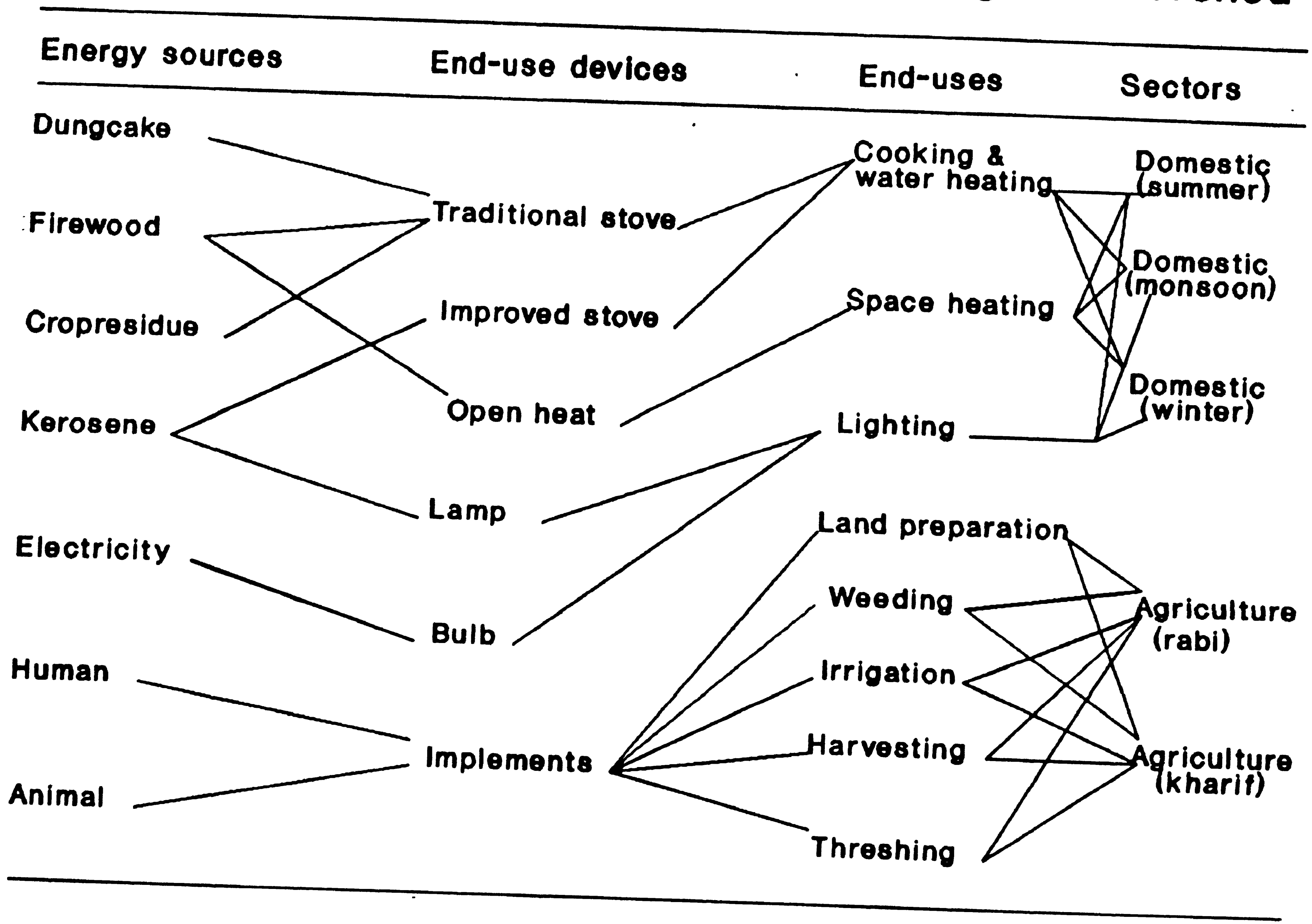
$G^{*(j)}$ = set of feasible combinations (i,k,j) for fixed end-use j, where i = 1,2,...7 and k = 1,2,...7

$G^{'(p)}$ = set of feasible combinations (i,j,k), i = 1,2,...7; k = 1,2,...7 and j = 1,2,...8, emitting p^{th} pollutant

Table 3.1 Definition of various indices considered in the model

Energy sources (i)	End-uses (j)	Devices (k)	Pollutants (p)	Animals (a)	Crops (c)	Land type (l)	Sectors (s)
Dungcake	Cooking and water heating	Traditional stove	Carbon monoxide	Cow	Paddy	Cultivable	Domestic (summer)
Firewood	Space heating	Improved stove	Suspended particulate matter	Calf	Mandwa	Pasture	Domestic (monsoon)
Crop residue	Lighting	Heater		Bullock	Sanwan	Forest	Domestic (winter)
Kerosene	Land preparation	Lamp		Buffalo	Maize	Homestead	Agriculture (rabi)
Electricity	Weeding	Bulb		Goat	Wheat		Agriculture (kharif)
Human	Irrigation	Animate		Sheep	Barley		
Animal	Harvesting	Thresher			Mustard		
	Threshing				Masoor		

Fig 3.2 Reference energy system for Shorgad watershed



3.3.2 Decision variables

For each feasible combination $(i,k,j) \in G$, let us define,

$y^{(s)}_{ikj}$ —

- daily per capita requirement of the i^{th} energy source for the j^{th} $(=1,2)$ end-use demand by the k^{th} type of device in the s^{th} sector; $s = 1,2,3$
- number of k^{th} devices required per household to meet the j^{th} $(=3)$ end-use demand using i^{th} energy in the s^{th} sector; $s = 1,2,3$
- per hectare requirement of the i^{th} energy source for the j^{th} $(=1,2,\ldots 7)$ end-use demand by the k^{th} type of implement in the s^{th} sector; $s = 4,5$
- per tonne requirement of the i^{th} energy source for the j^{th} $(=8)$ end-use demand by the k^{th} type of implement in the s^{th} sector; $s = 4,5$

Also, for $l = 1,2,\ldots 4$, define,

x_l = area covered under l^{th} type of land

In particular, when $l = 1$ and $c = 1,2,\ldots 8$

$x_{lc} = x_{1c}$ = area under cultivation of c^{th} type of crop, such that $x_1 = \sum_{c=1}^{8} x_{1c}$

3.3.3 Parameters

For each feasible combination $(i,k,j) \in G$, let us denote by $e^{(s)}_{ikj}$ the energy demand coefficient corresponding to the decision variable $y^{(s)}_{ikj}$. Depending upon a particular sector and/or end-use these coefficients are defined differently as given below :

$e^{(s)}_{ikj}$

- relative efficiency of the k^{th} device, expressed as a <u>fraction</u>, used to meet the j^{th} (=1,2) end-use demand by utilizing the i^{th} energy source; $s = 1,2,3$
- light output of the k^{th} device, expressed as <u>lumen</u>, used to meet the j^{th} $(j=3)$ end-use demand by utilizing the i^{th} energy source; $s = 1,2,3$

$f^{(s)}_{ikj}$

- conversion from original or physical units to energy units, expressed in <u>kilo Joules</u> (kJ), when i^{th} energy is consumed by the k^{th} device to meet the j^{th} (=1,2) end-use demand
- number of hours of k^{th} device used daily using i^{th} energy to meet the j^{th} (=3) end-use demand; $s = 1,2,3$
- conversion from bullock pair hour to <u>kJ</u> when i^{th} energy is consumed for the j^{th} (=4,5,...7) end-use using k^{th} implement; $s = 4,5$

Also, the parameters related to biomass production are defined as

y_c = productivity of the c^{th} crop, expressed as kg ha^{-1}; c = 1,2,...8

f_c = conversion from amount of c^{th} crop (grain) consumed (kg) to its calorific equivalent, expressed as kcal kg^{-1}; c = 1,2,...5,8

P = human population in the watershed

h_c = quantity of c^{th} type of crop residue produced from a unit mass of c^{th} crop grain, in other words, straw to grain ratio of the c^{th} crop; c = 1,2,...8

A_a = livestock population of a^{th} type in the Chamoli watershed; a = 1,2,...6

v_l = sustainable yield of firewood from l^{th} type of land; l = 1,3,4

t_a = time in <u>hours</u> spent by the a^{th} animal in one hectare of land; a = 1,2,4,5,6

u_a = fodder intake (in kg) by a^{th} animal for 1 hour of grazing, expressed in kg h^{-1}; a = 1,2,4,5,6

Finally, the environment related parameters, for each feasible combination (i,k,j) ∈ G are defined as,

$q^{(p,s)}{}_{ikj}$ = emission factor of the p^{th} pollutant, expressed in g kg^{-1} of i^{th} fuel consumed for the j^{th} end-use using k^{th} appliance in the s^{th} sector; p = 1,2

r_l = estimated soil loss from the l^{th} type of land, expressed in kg ha^{-1}; l = 1,2,3

3.3.4 Aspiration (target) level

Depending upon a particular sector and/or end-use, define

$D^{(s)}$ $\begin{cases} \text{- daily per capita useful energy demand, expressed in } \underline{\text{kJ}}\text{, for the } j^{th} \text{ (=1,2) end-use in the } s^{th} \text{ sector, s = 1,2,3} \\ \text{- daily per household useful light output, expressed in } \underline{\text{lumen hours}}\text{, for the } j^{th} \text{ (=3) end-use in the } s^{th} \text{ sector; s = 1,2,3} \\ \text{- energy required per hectare for the } j^{th} \text{ (=1,2,..7) end-use, expressed in kJ } ha^{-1}\text{, in the } s^{th} \text{ sector; s = 4,5} \\ \text{- energy required per tonne for the } j^{th} \text{ (=8) end-use, expressed in kJ } t^{-1}\text{, in the } s^{th} \text{ sector; s = 4,5} \end{cases}$

Also, let us define

E = daily per capita foodgrain required, expressed in <u>kcal</u>

F_a = daily fodder required by a^{th} type of animal, expressed in <u>kg</u>

W = total annual firewood available in the watershed expressed in <u>tonne</u>

E_1 = total annual crop residue available as fodder in the watershed, expressed in <u>tonne</u>

E_2 = total annual crop residue available as fuel in the watershed, expressed in <u>tonne</u>

Q = daily per capita dung available as fuel in the watershed, expressed in <u>kg</u>

$L^{(p)}$ = daily emission of the p^{th} pollutant due to burning of different fuels, expressed in kg

M = annual soil loss in the watershed, expressed in tonne

N_1 = area of the watershed, expressed in ha

T_1 = minimum area for grazing in watershed, expressed in ha

T_2 = area under forest, in ha

V_1 = basic requirement of wheat and rice together for balanced diet, expressed in calories

V_2 = basic requirement of pulses for a balanced diet, expressed in calories

N_2 = land area under human settlements in the watershed, expressed in ha

3.5 Constraints

Useful energy demand by sectoral end-use

The present level of useful energy consumption for each end-use in domestic and agricultural sector, estimated exogenously, must be met. Mathematically,

1. Domestic sector

$$\sum_{i \in G^*(j)} e^{(s)}_{ikj} f^{(s)}_{ikj} Y^{(s)}_{ikj} \geq D^{(s)}_j \quad \ldots (1)$$

where (j,s) takes values such that

$$(j,s) \in K_1 = \{(1,1),(1,2),(1,3),(2,2),(2,3),(3,1),(3,2),(3,3)\}$$

2. Agriculture sector

$$\sum_{i \in G^*(j)} f^{(s)}_{ikj} Y^{(s)}_{ikj} \geq D^{(s)}_j \quad \ldots (2)$$

where (j,s) takes values such that

$$(j,s) \in K_2 = \{(4,4),(4,5),(5,4),(5,5),(6,4),(6,5),(7,4),(7,5),(8,4),(8,5)\}$$

We have a total of 18 energy demand constrained inequalities in Eq (1) and Eq (2) together. Of these, 8 correspond to the domestic sector for cooking, water heating, space heating and lighting. The last 10 correspond to the agricultural sector for land preparation, weeding, irrigation, harvesting and threshing.

Nutritive value of foods

These constraints ensure that the requirement of foodgrain and fodder is to be met for meeting the minimum nutritional level, estimated by the nutrition expert group in 1968 (Gopalan et al, 1987). Mathematically,

1. Foodgrain requirement

$$\sum_{c} y_c f_c x_{1c} \geq E/P \quad ; \quad c = 1,2,..5,8 \qquad \ldots (3)$$

2. Fodder requirement

$$\sum_{c=1}^{6} y_c h_c x_{1c} + t_a u_a x_2 \geq F_a/A_a, \quad a = 1,2,\ldots 6 \qquad \ldots (4)$$

For goats and sheep $(a = 5,6)$, it is assumed that they are never stallfed. On the other hand $t_3 = 0$, as bullocks are never taken out for grazing and are always stall-fed.

We have a total of 7 constrained inequalities corresponding to Eq (3) and Eq (4) together. The first inequality corresponds to the basic foodgrain required for the watershed and the last six correspond to the fodder requirement for livestock.

Biomass resources potential

The total biomass resource available for use in the form of firewood and crop residue in the watershed is estimated from the area of land under forest and land under cultivation respectively. Mathematically,

1. Wood resource as fuel

$$\sum_{l} v_l x_l \leq W \qquad l = 1,3,4 \qquad \ldots (5)$$

2. Crop residue as fodder

$$\sum_{c} y_c h_c x_{1c} \leq E_1 \qquad c = 1,2,\ldots 6 \qquad \ldots (6)$$

3. Crop residue as fuel

$$\sum_{c} y_c h_c x_{1c} \leq E_2 \qquad c = 4,7,8 \qquad \ldots (7)$$

Inequalities (5), (6) and (7) together have 3 constraints, one each for wood resource and crop residue available as fuel and crop residue as fodder.

Supply-demand balance for biomass fuels

These constraints ensure that the total demand of different forms of biomass energy sources (namely, dungcake, crop residue and firewood) for different domestic end-uses cannot exceed their total availability in the watershed. Mathematically,

1. Dungcake

$$\sum_{j \in G^{(i)}} \sum_{s=1}^{3} y^{(s)}_{ikj} \leq Q \qquad i = 1 \qquad \ldots (8)$$

2. Crop residue

$$\sum_{j \in G^{(i)}} \sum_{s=1}^{3} y^{(s)}_{ikj} \leq E_2/P \qquad i = 4 \qquad \ldots (9)$$

3. Firewood

$$\sum_{j \in G^{(i)}} \sum_{s=1}^{3} y^{(s)}_{ikj} \leq F/P \qquad i = 2,3 \qquad \ldots (10)$$

We have here 3 constrained inequalities, one each of dungcake, crop residue and firewood respectively.

Environment

Here we have two types of constraints. First, the daily emissions of CO and SPM due to the burning of domestic fuels should not exceed their present levels. Second, the annual loss of soil must not exceed the present level. Mathematically,

1. Air pollution loading

$$\sum_{(ijk) \in G'^{(p)}} \sum_{s=1}^{3} q^{(s)}_{ikj} \, y^{(s)}_{ikj} \, P \leq L^{(p)} \qquad p = 1,2 \qquad \ldots (11)$$

2. Soil erosion

$$\sum_{c=1}^{8} r_1 x_{1c} + \sum_{1=2}^{3} r_1 x_1 \leq M \qquad \ldots (12)$$

There are 3 constrained inequalities in (11) and (12) together. Of these, 2 correspond to air pollution and one to soil erosion.

Grazing area

This constraint ensures that the grazing area in the Chamoli watershed must drop below a minimum level. Mathematically,

$$x_2 \geq T_1 \qquad \ldots (13)$$

Rigid constraints

We have considered in the model framework eight rigid constraints. These are:

1. Total land available

The sum of the area under different categories of land, namely cultivable, grazing, forest and homestead must always be equal to the total area of land in the watershed. Mathematically,

$$\sum_{c=1}^{8} x_{1c} + \sum_{l=2}^{3} x_l = N_1 \qquad \ldots (14)$$

2. Land under forest

Area under forest should not be allowed to drop below the present forest area. Mathematically,

$$x_3 = T_2 \qquad \ldots (15)$$

3. Wheat and rice consumption

The basic requirement of wheat and rice must be met and should be equal to the basic nutritive value. Mathematically,

$$\sum_{c} y_c f_c x_{1c} = V_1 \qquad c = 1 \text{ and } 5 \qquad \ldots (16)$$

4. Pulse consumption

The basic requirement of pulses must be met and should be equal to the basic nutritive value. Mathematically,

$$y_c f_c x_{1c} = V_2 \qquad \text{for } c = 8 \qquad \ldots (17)$$

5. Kerosene lamps

Each household in the watershed will have one kerosene lamp to partially meet their lighting demand.

Mathematically,

$$\sum_{s=1}^{3} y^{(s)}{}_{ikj} = 1 \qquad \text{for } i = 4,\ k = 4,\ j = 3 \qquad \ldots (18)$$

6. Homestead area

Area under homestead land must be equal to the present area under settlements.

$$x_l = V_2 \qquad \text{for } l = 4 \qquad \ldots (19)$$

Non-negativity constraint

We have here the natural constraints

$$y^{(s)}{}_{ikj} \geq 0 \qquad i,k,j \text{ and } s$$

$$x_l \geq 0 \qquad l$$

3.3.6 LGP framework

Generally, all these constraints, Eq (1) to (13), cannot be met simultaneously. Therefore, these constrained inequalities are transformed into equations by adding a negative deviational variable (denoted by d^- with different suffixes as indices) and subtracting a positive deviational variable (denoted by d^+ with different suffixes as indices) to the left side of each inequality. Thus, the constraints Eq (1) to (13) of the LGP model in the form of equations would be:

$$\sum_{i \in G^*(j)} e^{(s)}{}_{ikj}\, f^{(s)}{}_{ikj}\, y^{(s)}{}_{ikj} + d^-{}_{js} - d^+{}_{js} = D^{(s)}{}_j \qquad \ldots (20)$$

$$\sum_{i \in G^*(j)} f^{(s)}{}_{ikj}\, y^{(s)}{}_{ikj} + d^-{}_{js} - d^+{}_{js} = D^{(s)}{}_j \qquad \ldots (21)$$

$$\sum_{c} y_c f_c x_{1c} + d'^- - d'^+ = E/P \qquad \ldots (22)$$

$$\sum_{c=1}^{6} y_c h_c x_{1c} + t_a u_a x_2 + d^{*-}{}_a - d^{*+}{}_a = F_a/A_a \qquad ...(23)$$

$$\sum_{1} v_1 x_1 + d^-{}_* - d^+{}_* = W \qquad ...(24)$$

$$\sum_{c} y_c h_c x_{1c} + d^-{}_{**}' - d^+{}_{**} = E_1 \qquad ...(25)$$

$$\sum_{c} y_c h_c x_{1c} + d^{''-} - d^{''+} = E_2 \qquad ...(26)$$

$$\sum_{j \in G^{(i)}} \sum_{s=1}^{3} y^{(s)}{}_{ikj} + d^{*/-} - d^{*/+} = Q \qquad ...(27)$$

$$\sum_{j \in G^{(i)}} \sum_{s=1}^{3} y^{(s)}{}_{ikj} + d^{/*-} - d^{/*+} = E_2/P \qquad ...(28)$$

$$\sum_{j \in G^{(i)}} \sum_{s=1}^{3} y^{(s)}{}_{ikj} + d^{**-} - d^{**+} = W/P \qquad ...(29)$$

$$\sum_{(ikj) \in G'^{(p)}} \sum_{s} q^{(s)}{}_{ikj} y^{(s)}{}_{ikj} P + d^-{}_p - d^+{}_p = L^{(p)} \qquad ...(30)$$

$$\sum_{c=1}^{8} r_1 x_{1c} + \sum_{1=2}^{3} r_1 x_1 + d^{/-}{}_* - d^{/+}{}_* = M \qquad ...(31)$$

$$x_2 + d^{''-} - d^{''+} = T_1 \qquad ...(32)$$

where,

$d^-{}_{js}$ (or $d^+{}_{js}$) = under-achievement (or over-achievement) of the j^{th} end-use energy demand in the s^{th} sector.

$d^{/-}$ (or $d^{/+}$) = deficit (or surplus) of foodgrain available in the watershed for consumption.

$d^{*-}{}_a$ (or $d^{*+}{}_a$) = deficit (or surplus) of fodder available in the watershed for consumption by the a^{th} type of animal.

d^{-}_{*} (or d^{+}_{*}) = under-utilization (or over-utilization) of wood resource potential for fuel purpose.

d^{-}_{**} (or d^{+}_{**}) = under-utilization (or over-utilization) of crop residue potential for fodder purpose.

$d^{''-}$ (or $d^{''+}$) = under-utilization (or over-utilization) of crop residue potential for fuel purpose.

$d^{*/-}$ (or $d^{*/+}$) = under-utilization (or over-utilization) of dungcake.

$d^{/*-}$ (or $d^{/*+}$) = under-utilization (or over-utilization) of crop residue.

d^{**-} (or d^{**+}) = under-utilization (or over-utilization) of firewood.

d^{-}_{p} (or d^{+}_{p}) = marginal loading of the p^{th} pollutant below (or above) the present emission level.

$d^{/-}_{*}$ (or $d^{/+}_{*}$) = soil erosion below (or above) the present level of annual soil loss.

$d^{''-}_{*}$ (or $d^{''+}_{*}$) = under-utilization (or over-utilization) of the grazing area.

The values of the indices in Eq (20) to (32) are same as defined in the constrained set of inequalities (1) to (13) respectively.

3.3.7 Goal formulations

The objective function is to minimize the weighted deviation of sub-goals within each goal class (see **Section 3.2**). From the definition of each of the deviational variables in equation (20) to (32) six goal classes G_1 to G_6 are formulated. As mentioned earlier the LGP model will determine the optimal routing of:

(i) energy mix from supply to demand nodes of the RES for the watershed as depicted in **Figure 3.2**, and

(ii) land utilization pattern under five scenarios, by addressing the goals defined in **Section 3.1**.

For notational convenience, let us replace all the goal deviations in Eq (20) to (32) by d^-_w (≥ 0) for negative deviations and d^{+w} (≥ 0) for positive deviations. Thus, goal deviations corresponding to goal classes:

G_1 is d^-_w ; $w = 1,2,\ldots 18$

G_2 is d^-_w ; $w = 19,20,\ldots 25$

G_3 is d^-_w ; $w = 26,27,28$

G_4 is d^-_w ; $w = 29,30,31$

G_5 is d^+_w ; $w = 32,33,34$

G_6 is d^+_w ; $w = 35$

Thus, G_1 has 18 sub-goals, G_2 has 7 sub-goals, G_3, G_4 and G_5 each has 3 sub-goals and G_6 has 1 goal. Also, from the definition of deviational variables and the goals classes, we can safely assume :

$d^+_w = 0$ for $w = 1,2,\ldots 18,26,27,\ldots 31$

$d^-_w = 0$ for $w = 35$

The objective function of the LGP can be formulated only after the following are determined.

(i) ordinal ranking of the six goal classes G_1 to G_6, and their grouping according to priorities, and

(ii) assigning weighting factors to the goal deviation of each of the sub-goals within a goal class.

Prioritization of goal classes

On carefully examining the six goals it was found that the first five goals, G_1 to G_5, cannot be met simultaneously. Therefore, each of them had been assigned different levels of pre-emptive priorities $P_1, P_2, \ldots P_5$ depending upon the ordinal ranking of these goal classes. These pre-emptive priorities have the relationship of

$$P_1 \gg P_2 \gg \ldots . P_5$$

where, >> means "strictly greater than" (Lee, 1981). This implies that multiplying the priority relationship by n, however large, cannot make the lower-level goal as important as the higher goal.

It was decided to keep G_2 at P_1; G_1 at P_2; G_3 and G_6 at P_3; G_4 at P_4 and G_5 at P_5.

Objective weighting within priority grouping

Once the six goal classes are prioritized at different levels, the differential weights are assigned to of each of the goal deviations of sub-goals within a goal class based on subjective judgement (see **Table 3.2**).

Table 3.2 Values of the differential weights in the model

	Description	z^-_w	z^+_w
1	Cooking and water heating : Summer : Domestic	0.055	-
2	Cooking and water heating : Monsoon: Domestic	0.055	-
3	Cooking and water heating : Winter : Domestic	0.055	-
4	Space heating : Monsoon : Domestic	0.055	-
5	Space heating : Winter : Domestic	0.055	-
6	Lighting : Summer : Domestic	0.055	-
7	Lighting : Monsoon: Domestic	0.055	-
8	Lighting : Winter : Domestic	0.055	-
9	Land preparation : Rabi : Agriculture	0.055	-
10	Land preparation : Kharif : Agriculture	0.055	-
11	Weeding : Rabi : Agriculture	0.055	-
12	Weeding : Kharif : Agriculture	0.055	-
13	Irrigation : Rabi : Agriculture	0.055	-
14	Irrigation : Kharif : Agriculture	0.055	-
15	Harvesting : Rabi : Agriculture	0.055	-
16	Harvesting : Kharif : Agriculture	0.055	-
17	Threshing : Rabi : Agriculture	0.055	-
18	Threshing : Kharif : Agriculture	0.055	-
19	Foodgrain requirement	0.250	-
20	Fodder requirement : Cows	0.125	-
21	Fodder requirement : Calves	0.125	-
22	Fodder requirement : Bullocks	0.125	-
23	Fodder requirement : Buffaloes	0.125	-
24	Fodder requirement : Goat	0.125	-
25	Fodder requirement : Sheep	0.125	-
26	Production : Forest : Fuel	0.300	-
27	Production : Forest : Crop residue	0.300	-
28	Production : Forest : Fuel	0.300	-
29	Supply-demand balance:Dungcake	0.333	-
30	Supply-demand balance:Cropresidue	0.333	-
31	Supply-demand balance:Firewood	0.333	-
32	CO pollution emission	-	0.333
33	SPM pollution emission	-	0.333
34	Soil erosion	-	0.333
35	Area under homestead	-	0.100

Let z^-_w (or z^+_w) be the value of the differential weights assigned to the negative goal deviation d^-_w (or positive goal deviation d^+_w).

Let us define:

$Z^-_1 = \sum_{w=1}^{18} z^-_w d^-_w$ = weighted deviation of the 18 sub-goals in G_1.

$Z^-_2 = \sum_{w=19}^{25} z^-_w d^-_w$ = weighted deviation of the 7 sub-goals in G_2.

$Z^-_3 = \sum_{w=26}^{28} z^-_w d^-_w$ = weighted deviation of the 3 sub-goals in G_3.

$Z^-_4 = \sum_{w=27}^{31} z^-_w d^-_w$ = weighted deviation of the 3 sub-goals in G_4.

$Z^-_5 = \sum_{w=32}^{34} z^-_w d^-_w$ = weighted deviation of the 3 sub-goals in G_5.

$Z^-_6 = z^+_w d^+_w$ for $w=35$ = weighted deviation of the goal G_6.

The assumed values of the differential weights (out of a total of 1 within a priority level) is presented in Table 3.2.

3.3.8 Objective function

The structure of the objective function is

$$\text{Minimize} \quad Z = P_1 Z^-_2 + P_2 Z^-_1 + P_3(Z^-_3 + Z^-_6) + P_4 Z^-_4 + P_5 Z^-_5$$

The mathematical structure of the LGP, after analysing the RES of the Shorgad watershed for 1990, had a total of 43 linear equations with 44 decision variables. The total number of deviational variables was 45, of which 34 were negative deviations and 11 were positive deviations.

The solution set of LGP was determined by using a FORTRAN program developed by Lee (1976). Of the total 89 variables, only a maximum of 43 non-zero variables were basic variables which were determined in the optimum solution set; the remaining 46 variables, being non-basic, have zero values.

3.4 Database and assumptions

The model parameters, namely (i) aspiration levels and (ii) coefficients of the decision variables were estimated from the questionnaire based survey and other secondary sources. These estimated parameters for the Shorgad micro-watershed are then provided as input to the model.

The parameters required for the model set up are discussed in the following sections.

3.4.1 Energy units and conversion factors

There is a variety of energy sources in the micro-watershed. To facilitate aggregation and comparison while dealing with different types of fuels, each source of energy is converted into its joule equivalent (**Table 3.3**). The efficiency of utilization of these energy sources are also presented in **Table 3.3**.

Table 3.3 Energy conversion table

Energy Source		Conversion norm
Biomass		
Dungcake	$kJ\ kg^{-1}$	8918 (8%)
Firewood	$kJ\ kg^{-1}$	19700 (11%)
Crop residue	$kJ\ kg^{-1}$	14654 (9%)
Non Biomass		
Kerosene	$kJ\ l^{-1}$	35785 (45%)*
LPG	$kJ\ kg^{-1}$	45217 (55%)
Electricity	$kJ\ kwh^{-1}$	3600 -
Human	$kJ\ manh^{-1}$	1959 -
Animal	kJ bullock pair h^{-1}	10195 -

Figures within parenthesis are assumed device efficiencies.
* Cooking device only
Source : NCAER (1978-79)

3.4.2 Parameters estimated from primary sources

Energy demand

1. Domestic sector

Useful energy demand for domestic end-uses like, cooking (including water heating), space heating and lighting by each category had been calculated from the survey data. The efficiency of utilization of different devices was assumed. End-use energy demands are estimated separately for summer, monsoon and winter season and are presented in **Table 3.4.** In the model the different fuel options presently available to meet these end-use demands and the efficiency of devices had been added.

Table 3.4 Per capita energy consumption pattern for various end-uses in different seasons: domestic sector

Activities	Unit	Cooking and water heating			Space heating		Lighting		
		Summer	Monsoon	Winter	Monsoon	Winter	Summer	Monsoon	Winter
Biomass									
Dungcake	kg day^{-1}	0.01 (0.09) ((0.01))	0.01 (0.09) ((0.01))	0.02 (0.18) ((0.01))	- - -	- - -	- - -	- - -	- - -
Firewood	kg day^{-1}	2.19 (43.10) ((4.35))	2.55 (50.19) ((5.06))	3.23 (63.58) ((6.41))	0.03 (0.59) ((0.059))	0.65 (12.79) ((1.29))	- - -	- - -	- - -
Crop residue	kg day^{-1}	-	-	0.11 (0.61) ((0.16))	-	-	-	-	-
Non Biomass									
Kerosene	l day^{-1}	0.02 (0.72) ((0.32))	0.02 (0.72) ((0.32))	0.02 (0.72) ((0.32))	-	-	0.01 (0.36)	0.011 (0.39)	0.011 (0.39)
Electricity	kWh day^{-1}	-	-	-	-	-	0.06 (0.22)	0.06 (0.22)	0.07 (0.25)
Total		(43.91) ((4.68))	(51.00) ((5.39))	(66.09) ((6.90))	(0.59) ((0.059))	(12.79) ((1.29))	(0.58)	(0.61)	(0.64)

Figures in single parenthesis are gross energy consumption and in double parenthesis are useful energy consumption and are both expressed in MJ day^{-1} $person^{-1}$.
Source : Survey data

2. Agriculture sector

Again, from the survey data, energy requirements for land preparation, irrigation, weeding and harvesting had been determined. For threshing, energy requirement per tonne of grain threshed had also been estimated. Energy input going in for these agricultural activities were worked out separately for Rabi (November to March) and Kharif (June to November) seasons and are presented in Table 3.5.

Table 3.5 Energy consumption pattern for various activities in different seasons: agricultural sector

Activities	Unit	Rabi			Kharif		
		Human	Animal	Total	Human	Animal	Total
Land preparation	MJ ha^{-1}	421	789	1210	431	399	1191
	man h ha^{-1}	221	-	221	226	-	226
	Bullock pair h ha^{-1}	-	79	79	-	211	211
Weeding	MJ ha^{-1}	-	-	-	1149	-	1149
	man h ha^{-1}	-	-	-	607	-	607
	Bullock pair h ha^{-1}	-	-	-	-	-	-
Irrigation	MJ ha^{-1}	11	-	11	20	-	20
	man h ha^{-1}	5	-	5	10	-	10
	Bullock pair h ha^{-1}	-	-	-	-	-	-
Harvesting	MJ ha^{-1}	277	-	277	328	-	328
	man h ha^{-1}	145	-	145	173	-	173
	Bullock pair h ha^{-1}	-	-	-	-	-	-
Threshing	MJ ha^{-1}	303	329	632	251	201	452
	man h ha^{-1}	149	-	149	128	-	128
	Bullock pair h ha^{-1}	-	31	31	-	19	19

Source : Survey data

The options available to meet these end-use energy requirement is specified in the model structure.

<u>Availability of biomass resources</u>

1. Crop residue

The availability of crop residue is determined endogenously by the model under each of the scenarios, depending upon the types of crop produced and area under cultivation as indicated by the solution. This crop residue is differentiated into crop residue for fuel and crop residue as fodder.

However, from the survey data, total production of crop residue as fuel and fodder (based on the existing area under cultivation of different crops and their corresponding yield) in the watershed were estimated (Table 3.6) and is provided as an input to the model structure. These production figures indicate locally available crop residue for use in the watershed.

Table 3.6 Total crop residue production in Shorgad

Crop particulars	Area (ha)	Yield ($t\ ha^{-1}$)	Grain yield (t)	Biomass conversion	Biomass yield as crop residue (t)
Kharif					
Paddy	376	2.4	917.4	1.57	1440**
Mandwa	324	1.6	528.1	1.20	634**
Sawan	54	1.7	93.4	1.20	112**
Maize	6	1.3	7.9	1.56	12*
Rabi					
Wheat	350	1.4	479.5	1.47	705**
Barley	15	1.2	18.3	1.47	27**
Mustard	3	0.6	1.8	1.85	3*
Masoor	5	0.7	3.3	1.30	4*

** Biomass used as fodder and
* Biomass used as fuel

2. Dung

Total dung availability in the watershed was estimated on the basis of the number of animals of a particular type

and the daily dung output per animal of each type (Table 3.7). Total production of dung was differentiated into dung consumed as fuel (in the form of dung cake) and dung used in as manure, again on the basis of survey data. Thus, the total dung cake produced locally, was taken as the upper bound for dung cake as a fuel option to meet cooking and water heating demand.

Table 3.7 Estimated availability of dung by different animals

Type of cattle	Numbers	Daily dung yield (kg animal^{-1})	Daily dung produced (kg)
Cow	821	3.5	2874
Calf	782	1.2	938
Bullock	1660	4.2	6972
Buffalo	1007	6.7	6747
Total			17531

Note : In addition to this the watershed has 1666 goats and 699 sheep.
Source : Survey data

3. Firewood

Total availability of firewood was determined endogenously by the model under alternate land use pattern.

But from the survey data, total firewood produced in the Shorgad watershed was estimated based on the present land utilization pattern and is presented in **Table 3.8**.

Table 3.8 Estimated annual availability of firewood from different types of land

Land type	Covered area (ha)	Sustainable firewood yield $(t\ ha^{-1})$	Total firewood production (t)
Forest	491	1.5	737
Cultivable	890	1.0	890
Homestead	54	2.0	108
Total			1735

Source : Survey data

4. Foodgrain requirement

As recommended by the Nutrition Expert Group, 1968 (Gopalan, Rama Sastri and Balasubramanian, 1987), the daily allowances of nutrients is around 3000 calories per capita daily. The same norm has been taken as the minimum foodgrain requirement per person daily in the micro-watershed.

<u>Fodder requirement</u>

Daily fodder consumption by different types of cattle were estimated from the survey data and is presented in Table 3.9.

Table 3.9 Daily fodder requirement by an animal

Animal type	kg
Cow	19.9
Calf	7.4
Bullock	24.8
Goat	32.4
Goat	2.0
Sheep	3.0

Source : Survey data

3.4.3 Parameters estimated from secondary data

<u>Lighting</u>

Owing to lack of data on inventory of lighting appliances in use in the watershed, we assumed the following:

1. Average number of electric bulbs per household = 2
2. Power of one bulb (W) = 40
3. Light intensity (Lumens per watt)* = 10
4. Average daily usage (h)
   - (i) Summer = 4
   - (ii) Monsoon = 4.5
   - (iii) Winter = 5

* see (Rajvanshi, 1987).

Thus, the daily lighting demand per household was found to be

(i) Summer = 3200 lumen h

(ii) Monsoon = 3600 lumen h

(iii) Winter = 4000 lumen h

In addition, it was assumed that every household in Shorgad has at least one kerosene lamp to meet part of their lighting demand.

Energy use and environmental effects

Annual emissions of CO and SPM were estimated on the basis of present usage of different type of fuels and their corresponding emission factors, and are presented in **Table 3.10**.

Table 3.10 Estimated emissions of CO and SPM due to combustion of different fuels

Fuel type	Emission factor			Annual emissions (t)	
	Unit	CO	SPM	CO	SPM
Dungcake	$g\ kg^{-1}$	30	5	1.5	0.3
Firewood	$g\ kg^{-1}$	20	2	221.9	22.2
Crop residue	$g\ kg^{-1}$	25	3	3.5	0.4
Kerosene	$g\ l^{-1}$	72	4	5.5	3.1
Total				232.4	26.0

Soil erosion

Soil loss from different land uses was estimated on the basis of their soil erosion intensity (Watershed Management Directorate 1988) and is presented in **Table 3.11**.

Table 3.11 Estimated annual soil loss from different land types

Land type	Covered area (ha)	Soil loss per hectare ($t\ ha^{-1}$)	Total soil loss (t)
Forest	491	0.09	44
Cultivable	890	1.0	890
Pasture	232	2.0	646
Total			1580

3.5 Results and conclusions

The model was used to illustrate the applicability of LGP to (i) land use planning and (ii) energy demand in the domestic and agricultural sector of the Shorgad micro-watershed. Six goals are considered in the following order of importance: (1) nutrition level, (2) energy demand, (3) sustainable biomass production, (4) meet energy demand locally, (5) reduce emission and erosion, and (6) grazing area not to drop below 100 ha.

For illustrative purposes, the model was run under five different scenarios as given below :

Scenario 1 : Business as usual or scenario where the existing land use pattern is considered, i.e., area under forest as 28%.

Scenario 2 : Forest area to increase by 33% of the total area.

Scenario 3 : Forest area to increase by 50% of the total area.

Scenario 4 : Forest area to increase by 55% of the total area.

Scenario 5 : Forest area to increase by 66% of the total area.

The model results under different scenarios are highlighted in **Tables 3.12** and **3.13** respectively.

3.5.1 End-use energy consumption pattern

In all the scenarios the present level of energy demand in both domestic and agriculture sector is fully met primarily because the energy demand goal is kept at a very high priority (P_2). The fuel mix pattern for various end-uses, namely cooking and water heating, space heating and lighting in the domestic sector and land preparation, weeding, irrigation, harvesting and threshing in the agriculture sector, remains the same. The mix of energy consumption varies across different seasons and is presented in **Table 3.14** for the domestic sector and **Table 3.15** for the agriculture sector.

Table 3.12 Deviation from goals under five different scenarios

Sgn. no.	Goal constraints	Unit	Goals	Priority & weight	Scenario 1 d^-	Scenario 1 d^+	Scenario 2 d^-	Scenario 2 d^+	Scenario 3 d^-	Scenario 3 d^+	Scenario 4 d^-	Scenario 4 d^+	Scenario 5 d^-	Scenario 5 d^+
1	Cooking and water heating : Domestic : Summer	10^3kJ/cap/day	4.68	0.06 P_2d^-	-	-	-	-	-	-	-	-	-	-
2	Cooking and water Heating : Domestic : Monsoon	10^3kJ/cap/day	5.39	0.06 P_2d^-	-	-	-	-	-	-	-	-	-	-
3	Cooking and water Heating : Domestic : Winter	10^3kJ/cap/day	6.91	0.06 P_2d^-	-	-	-	-	-	-	-	-	-	-
4	Space heating : Domestic : Monsoon	10^3kJ/cap/day	0.06	0.06 P_2d^-	-	-	-	-	-	-	-	-	-	-
5	Space heating : Domestic : Winter	10^3kJ/cap/day	1.29	0.06 P_2d^-	-	-	-	-	-	-	-	-	-	-
6	Lighting : Domestic : Summer	10^3ltr/hh/day	3.2	0.06 P_2d^-	-	-	-	-	-	-	-	-	-	-
7	Lighting : Domestic : Monsoon	10^3ltr/hh/day	3.5	0.06 P_2d^-	-	-	-	-	-	-	-	-	-	-
8	Lighting : Domestic : Winter	10^3ltr/hh/day	4.8	0.06 P_2d^-	-	-	-	-	-	-	-	-	-	-
9	Land preparation : Agriculture : Rabi	10^3kJ/ha	1210	0.06 P_2d^-	-	-	-	-	-	-	-	-	-	-
10	Land preparation : Agriculture : Kharif	10^3kJ/ha	1191	0.06 P_2d^-	-	-	-	-	-	-	-	-	-	-
11	Weeding : Agriculture : Rabi	10^3kJ/ha	50	0.06 P_2d^-	-	-	-	-	-	-	-	-	-	-
12	Weeding : Agriculture : Kharif	10^3kJ/ha	1149	0.06 P_2d^-	-	-	-	-	-	-	-	-	-	-
13	Irrigation : Agriculture : Rabi	10^3kJ/ha	11	0.06 P_2d^-	-	-	-	-	-	-	-	-	-	-
14	Irrigation : Agriculture : Kharif	10^3kJ/ha	20	0.06 P_2d^-	-	-	-	-	-	-	-	-	-	-
15	Harvesting : Agriculture : Rabi	10^3kJ/ha	277	0.06 P_2d^-	-	-	-	-	-	-	-	-	-	-
16	Harvesting : Agriculture : Kharif	10^3kJ/ha	328	0.06 P_2d^-	-	-	-	-	-	-	-	-	-	-
17	Threshing : Agriculture : Rabi	10^3kJ/tonne	632	0.06 P_2d^-	-	-	-	-	-	-	-	-	-	-
18	Threshing : Agriculture : Kharif	10^3kJ/tonne	452	0.06 P_2d^-	-	-	-	-	-	-	-	-	-	-
19	Foodgrain requirement	10^3kCal/cap/day	3	0.25 P_1d^-	1.29	-	1.34	-	2.53	-	2.6	-	3	-
20	Fodder requirement : Grazing & Stall : Cows	kg/cow/day	19.9	0.125 P_1d^-	-	151.29	-	175.75	-	242.75	-	262.54	-	280.77
21	Fodder requirement : Grazing & Stall : Calf	kg/calf/day	7.4	0.125 P_1d^-	-	99.29	-	110.95	-	151.55	-	163.04	-	173
22	Fodder requirement : Stall : Bullock	kg/bullock/day	24.8	0.125 P_1d^-	21.26	-	20.35	-	22.95	-	23.74	-	24.8	-
23	Fodder requirement : Grazing & Stall : Buffalo	kg buffalo/day	32.4	0.125 P_1d^-	-	203.16	-	272.62	-	383.39	-	417.77	-	443.67
24	Fodder requirement : Grazing : Goat	kg/goat/day	2	0.125 P_1d^-	-	320.5	-	[illegible]	-	514.5	-	558.50	-	599.33
25	Fodder requirement : Grazing : Sheep	kg/sheep/day	3	0.125 P_1d^-	-	319.5	-	[illegible]	-	513.5	-	557.50	-	598.33
26	Production : Forest : Fuel	tonne/year	1735	0.3 P_3d^-	-	-	-	-	-	-	-	-	-	-
27	Production : Crop residue : Fodder	tonne/year	2913	0.3 P_3d^-	-	-	75.14	-	1706.45	-	2242.09	-	2919	-
28	Production : Crop residue : Fuel	tonne/year	19	0.3 P_3d^-	-	-	19	-	19	-	19	-	19	-
29	Balance : Dungcake	kg/cap/day	3.04	0.33 P_4d^-	-	-	-	-	-	-	-	-	-	-
30	Balance : Crop residue	kg/cap/day	0.53	0.33 P_4d^-	-	-	-	-	-	-	-	-	-	-
31	Balance : Firewood	kg/cap/day	1	0.33 P_4d^+	-	-	-	-	-	-	-	-	-	-
32	CO Pollutant : Loading	kg/day	645	0.33 P_5d^+	-	450.18	-	450.18	-	450.19	-	450.19	-	450.18
33	SPM Pollutant : Loading	kg/day	72	0.33 P_5d^+	-	8.95	-	8.95	-	8.95	-	8.95	-	9.96
34	Soil erosion	tonne/year	158	0.33 P_5d^+	.31	-	[illegible]	-	[illegible]	-	195.47	-	270.23	-
35	Land balance	ha	1753	E	-	-		-	-	-	-	-	-	-
36	Minimum forest land	ha	1	E	-	-	-	[illegible]	-	-	-	-	3.33	-
37	Minimum grazing land	ha	100	0.1 P_3d^+	-	222.5	-	-	-	416.5	-	460.5	-	501.33
38	Padd. + wheat consumption	10^3kCal/day	28.57	E	10.19	-	[illegible]	-	21.17	-	24.33	-	28.57	-
39	Pulse (Masoor) consumption	10^3kCal/day	6.12	E	5.9	-	6.12	-	6.12	-	6.12	-	6.12	-
40	Kerosene : Lamp : Light : Dom : Summer	no. lamps hh	1	E	-	-	-	-	-	-	-	-	-	-
41	Kerosene : Lamp : Light : Dom : Monsoon	no. lamps hh	1	E	-	-	-	-	-	-	-	-	-	-
42	Kerosene : Lamp : Light : Dom : Winter	no. lamps hh	1	E	-	-	-	-	-	-	-	-	-	-
43	Area under homestead land	ha	54	E	-	-	-	-	-	-	-	-	54	-

\ Scenario 1 = 33% under forest area; Scenario 2 = 33% under forest area; Scenario 3 = 50% under forest area; Scenario 4 = 55% under forest area; Scenario 5 = 60% under forest area;
E denotes equality constraints

Table 3.13 Scenario results (i) energy mix in the domestic and agriculture sector and (ii) land use pattern

Sl. no.	Decision variables	Unit	Business as usual	Scenario 1	Scenario 2*	Scenario 3	Scenario 4	Scenario 5
1	Dungcake : Cook + Water heating : Dom : Sum	kg/cap/day	0.01	0.04	0.04	0.04	0.04	0.04
2	FW : Logs : Cook + Water heating : Dom : Sum	kg/cap/day	0.09	0.43	0.43	0.43	0.43	0.43
3	FW : Twigs : Cook + Water heating : Dom : Sum	kg/cap/day	2.1	-	-	-	-	-
4	Crop residue : Cook + Water heating : Dom : Sum	kg/cap/day	-	0.53	0.53	0.53	0.53	0.53
5	Kerosene : Cook + Water heating : Dom : Sum	lit/cap/day	0.02	0.18	0.18	0.18	0.18	0.18
6	LPG : Cook + Water heating : Dom : Sum	kg/cap/day	-	-	-	-	-	-
7	Dungcake : Cook + Water heating : Dom : Mon	kg/cap/day	0.02	-	-	-	-	-
8	FW : Logs : Cook + Water heating : Dom : Mon	kg/cap/day	0.12	-	-	-	-	-
9	FW : Twigs : Cook + Water heating : Dom : Mon	kg/cap/day	3.11	-	-	-	-	-
10	Crop residue : Cook + Water heating : Dom : Mon	kg/cap/day	0.11	-	-	-	-	-
11	Kerosene : Cook + Water heating : Dom : Mon	lit/cap/day	0.02	0.33	0.33	0.33	0.33	0.33
12	LPG : Cook + Water heating : Dom : Mon	kg/cap/day	-	-	-	-	-	-
13	Dungcake : Cook + Water heating : Dom : Win	kg/cap/day	0.01	-	-	-	-	-
14	FW : Logs : Cook + Water heating : Dom : Win	kg/cap/day	0.1	-	-	-	-	-
15	FW : Twigs : Cook + Water heating : Dom : Win	kg/cap/day	2.45	-	-	-	-	-
16	Crop residue : Cook + Water heating : Dom : Win	kg/cap/day	-	-	-	-	-	-
17	Kerosene : Cook + Water heating : Dom : Win	lit/cap/day	0.02	0.43	0.43	0.43	0.43	0.43
18	LPG : Cook + Water heating : Dom : Win	kg/cap/day	-	-	-	-	-	-
19	FW : Logs : Space heating : Dom : Mon	kg/hh/day	-	0.03	0.03	0.03	0.03	0.03
20	FW : Twigs : Space heating : Dom : Mon	kg/hh/day	0.03	-	-	-	-	-
21	FW : Logs : Space heating : Dom : Win	kg/hh/day	0.03	0.54	0.54	0.54	0.54	0.54
22	FW : Twigs : Space heating : Dom : Win	kg/hh/day	0.62	-	-	-	-	-
23	Kerosene : Lighting : Dom : Sum	# lamps/hh/day	na	1	1	1	1	1
24	Ele. 40 W Bulb : Lighting : Dom : Sum	# lamps/hh/day	na	1.83	1.83	1.83	1.83	1.83
25	Kerosene : Lighting : Dom : Mon	# lamps/hh/day	na	1	1	1	1	1
26	Ele. 40 W Bulb : Lighting : Dom : Mon	# lamps/hh/day	na	2.08	2.08	2.08	2.08	2.08
27	Kerosene : Lighting : Dom : Win	# lamps/hh/day	na	1	1	1	1	1
28	Ele. 40 W Bulb : Lighting : Dom : Win	# lamps/hh/day	na	2.33	2.33	2.33	2.33	2.33
29	Human : Land Prep : Agr : Rabi	M hrs/ha	221	-	-	-	-	-
30	Animal : Land Prep : Agr : Rabi	BP hrs/ha	79	118.63	118.63	118.63	118.63	118.63
31	Human : Land Prep : Agr : Kharif	M hrs/ha	226	-	-	-	-	-
32	Animal : Land Prep : Agr : Kharif	BP hrs/ha	76	116.76	116.76	116.76	116.76	116.76
33	Human Weeding : Agr : Rabi	M hrs/ha	na	25.51	25.51	25.51	25.51	25.51
34	Human Weeding : Agr : Kharif	M hrs/ha	607	586.22	586.22	586.22	586.22	586.22
35	Human : Irrigation : Agr : Rabi	M hrs/ha	5	5.61	5.61	5.61	5.61	5.61
36	Human : Irrigation : Agr : Kharif	M hrs/ha	10	10.2	10.2	10.2	10.2	10.2

Table 3.13 (Continued) Scenario results (i) energy mix in the domestic and agriculture sector and (ii) land use pattern

Sl. no.	Decision variables	Unit	Business as usual	Scenario 1	2	3	4	5
37	Human : Harvesting : Agr : Rabi	M hrs/ha	145	141.33	141.33	141.33	141.33	141.33
38	Human : Harvesting : Agr : Kharif	M hrs/ha	173	167.35	167.35	167.35	167.35	167.35
39	Human : Threshing : Agr : Rabi	M hrs/tonne	149	-	-	-	-	-
40	Animal : Threshing : Agr : Rabi	BP hrs/tonne	31	61.96	61.96	61.96	61.96	61.96
41	Human : Threshing : Agr : Kharif	M hrs/tonne	128	-	-	-	-	-
42	Animal : Threshing : Agr : Kharif	BP hrs/tonne	19	44.31	44.31	44.31	44.31	44.31
43	Cultivable land : Paddy	ha	na	644.23	742	308.5	176.5	-
44	Cultivable land : Mandwa	ha	na	-	-	-	-	-
45	Cultivable land : Sanwan	ha	na	-	-	-	-	-
46	Cultivable land : Maize	ha	na	-	-	-	-	-
47	Cultivable land : Wheat	ha	na	224.18	-	-	-	-
48	Cultivable land : Barley	ha	na	-	-	-	-	-
49	Cultivable land : Mustard	ha	na	-	-	-	-	-
50	Cultivable land : Masoor	ha	na	22.1	-	-	-	-
	Total cultivable land	ha	890	890.51	742	308.5	176.5	-
51	Grazing land	ha	323	322.5	372	516.5	560.5	601.33
52	Forest land	ha	491	491	590	879	967.5	1156.67
53	Homestead land	ha	54	54	54	54	54	54

na denotes not available

The results from Table 3.14 can be summarized as follows:

1. Firewood is mainly consumed in the form of twigs in the watershed. Its share remained same (96%) in all the three seasons, the remaining share of 4% is consumed in the form of logs.
2. Due to lack of data on inventory of electrical appliances, it is assumed that energy household has one kerosene lamp to meet part of their lighting demand.

3. Domestic energy consumption for all end-uses during winter is always maximum and in summer it is minimum. The seasonal difference in energy demand for cooking and water heating is 47%, whereas for lighting the difference is 27%. Also, a substantial amount of energy in terms of firewood (twigs) us used for space heating during winter.

4. The model picks up only kerosene to meet the cooking and water heating requirement during monsoon and winter seasons. No firewood is consumed to meet the cooking and water heating requirement. In fact, firewood collected is consumed for space heating only.

Table 3.14 Domestic energy consumption pattern

		Present consumption	Model	Present consumption	Model	Present consumption	Model
Cooking and water heating							
Dung cake	kg cap^{-1} day^{-1}	-	0.04	0.02	-	0.01	-
Firewood[1]	kg cap^{-1} day^{-1}	-	0.43	3.23	-	2.55	-
Crop residue	kg cap^{-1} day^{-1}	-	0.53	0.11	-	-	-
Kerosene	lt cap^{-1} day^{-1}	-	0.18	0.02	0.33	0.02	0.43
Space heating							
Firewood[1]	kg hh^{-1} day^{-1}	-	-	0.03	0.03	0.54	0.54
Lighting							
Kerosene lantern[2]	# lamps hh^{-1} day^{-1}	n.a.	1.00	n.a.	1.00	n.a.	1.00
Electric bulb	# 40 watt bulbs hh^{-1} day^{-1}	n.a.	1.83	n.a.	2.08	n.a.	2.33

Table 3.15 Agricultural energy consumption pattern

		Rabi		Kharif	
		Present level	Model	Present level	Model
Land preparation					
Human	Man hr ha^{-1}	221	-	226	-
Animal	BP hr ha^{-1}	79	118.63	76	116.76
Weeding					
Human	Man hr ha^{-1}	22	25.51	607	586.22
Irrigation					
Human	Man hr ha^{-1}	5	5.0	10	10.20
Harvesting					
Human	Man hr ha^{-1}	145	141.33	173	167.35
Threshing					
Human	Man hr t^{-1}	149	-	128	-
Animal	BP hr t^{-1}	31	61.96	19	44.31

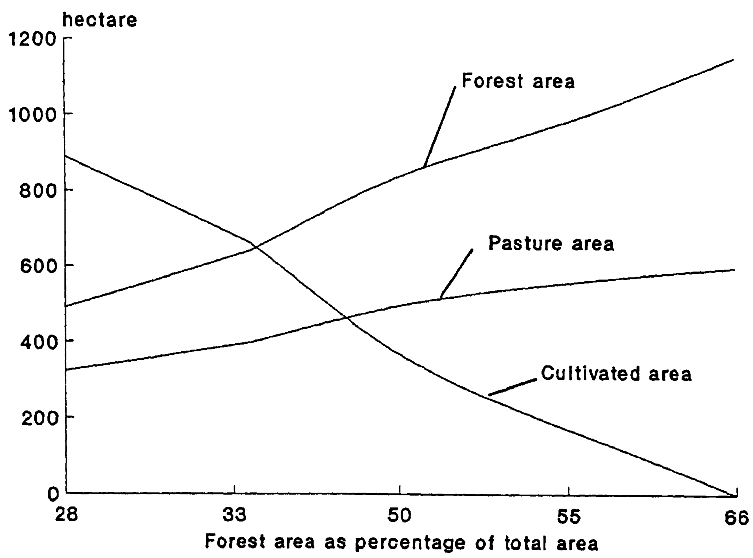
The results from **Table 3.15** can be summarized as follows:

1. We have not imposed any upper bound for number of human labour or animals (bullock power) available in the watershed. According to the model result, if both human and animal energy are kept as options for meeting the energy demand for a specific agricultural activity, be it land preparation or threshing, always bullock pair as an energy source is picked up by the model.
2. Apart from threshing, energy consumption per hectare of different agricultural activities is always higher in kharif than in rabi season. Whereas, for threshing, energy consumption per tonne of grains threshed is higher in rabi season than in kharif.

3.5.2 Land use pattern

Interestingly, as we move from scenario 1 (i.e. area under forest 28%) to scenario 5 (i.e. area under forest 66%), the area under cultivation decreased consistently. Whereas, area under grazing increased as can be seen in **Figure 3.3.** This has resulted in a local imbalance between the supply and demand of foodgrain for consumption and also fodder required by animals as crop residue.

Fig 3.3 Land utilization pattern

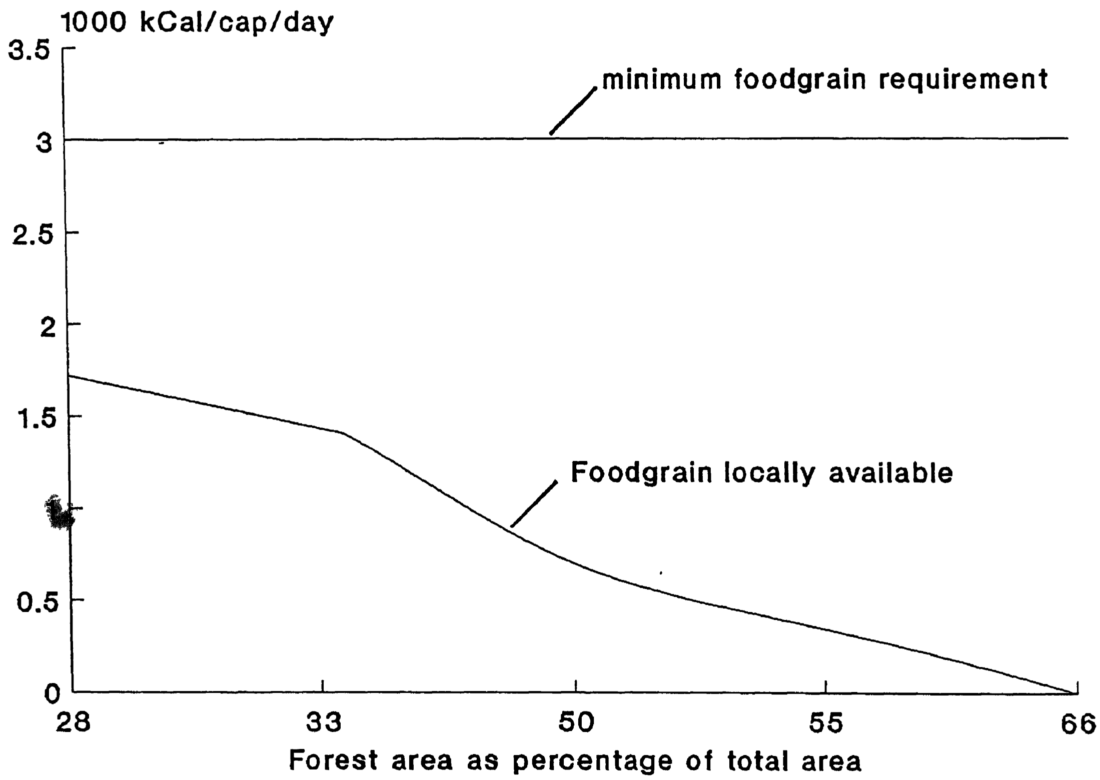


3.5.3 Nutritional demand

In none of the scenarios, minimum nutritional demand in terms of foodgrains requirement for the people of Shorgad is locally being met (**Figure 3.4**). With more and more area under forest, the production of crops decreased. With the present area under forest cover (28% of the total area - scenario 1), locally produced foodgrain for consumption is 34% less than the supply. The supply-

demand gap increases further with greater area under forest. In fact, under scenario 5 the crop production level is zero because of non-availability of cultivable land (Figure 3.3). Thus, to bring the fraction of area under forest to nearly 2/3rd is not practically feasible proposition for Shorgad.

Fig 3.4 Foodgrain requirement vs. availability



3.5.4 Fodder requirement

The fodder requirement for cows, calves, buffaloes, goats, sheep is met either from grazing or stall feeding. Whereas for bullocks, the fodder demand is met only through stall feeding. The stall-fed fodder are mainly crop residues produced after harvesting. As area under forest increases, more area also comes under pasture land. It is observed that the fodder demand is easily met mainly

from pasture land for all animals excepting bullock. However, for bullocks availability of stall-fed fodder decreases drastically with increase in forest area as can be seen in **Figures 3.5 and 3.6.**

Fig 3.5 Crop residue available as fodder

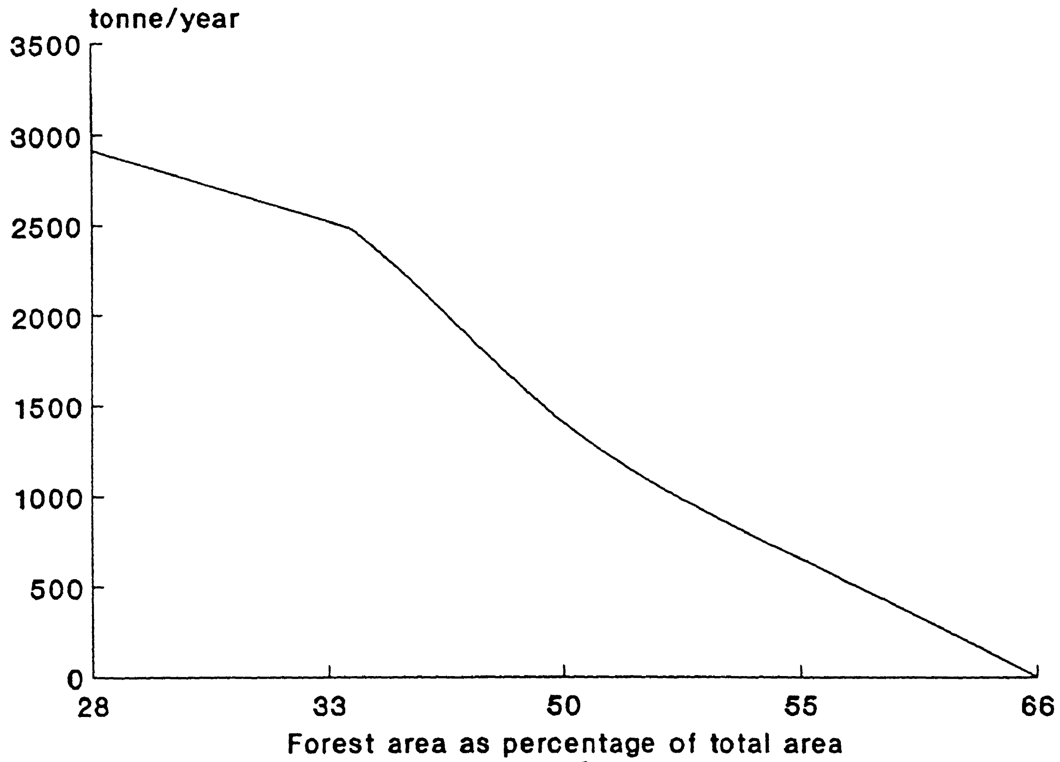
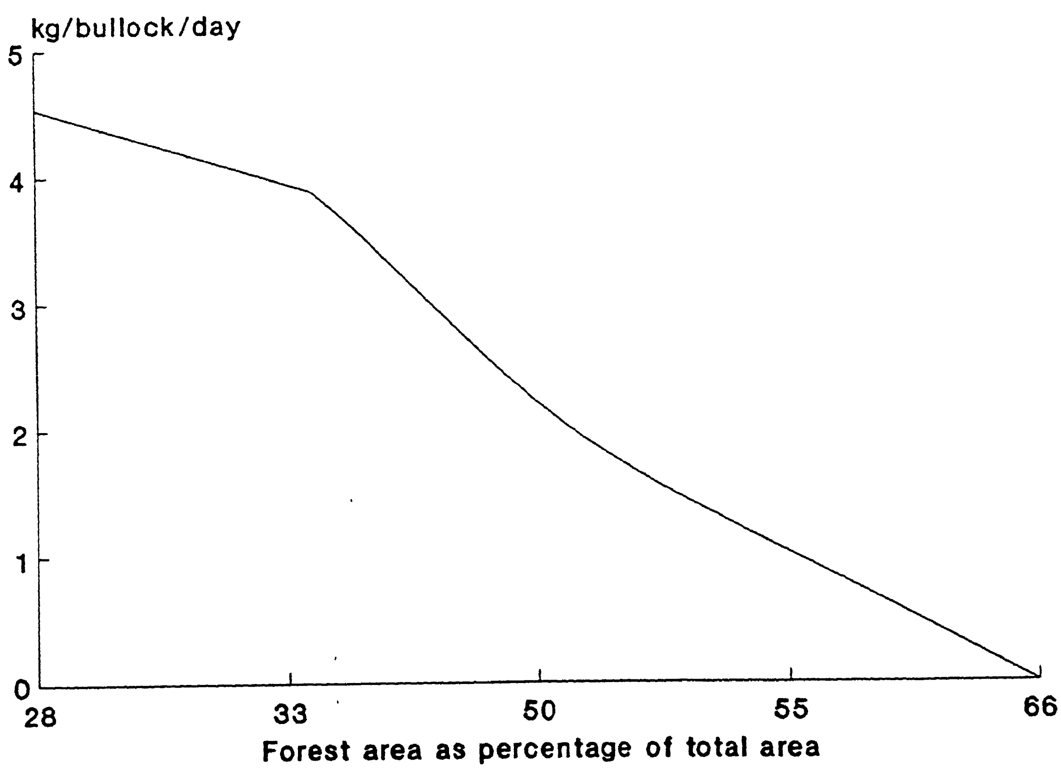


Fig 3.6 Stallfed fodder consumption by bullock



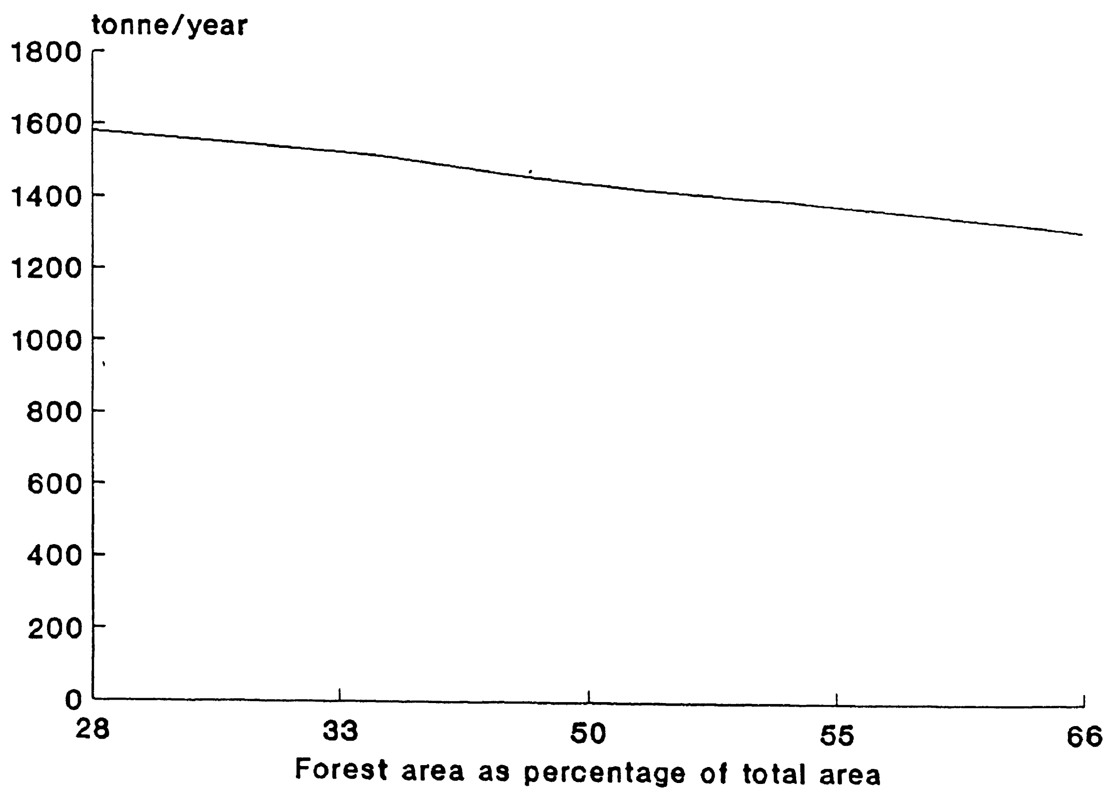
3.5.5 CO and SPM emission

Interestingly, irrespective of the increase in forest area from 28% to 66%, the pollution emission of CO and SPM remained at levels 70% and 12% higher, than the present emission levels, respectively. The reason being that the pollution related goal is assigned the least importance.

3.5.6 Soil erosion

With an increase in forest area from 28% to 66% there is a marginal decline in the extent of annual soil loss as can be seen from **Figure 3.7**. With 28% forest area, the extent of soil erosion was 0.01% less than the present level of soil erosion. However, when the forest area is taken as 66% the extent of soil loss declined to 17.3% with respect to the present level of soil erosion.

Fig 3.7 Annual soil loss



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Appendix 3.1

Physical features of the Shorgad micro-watershed

1.	District	Chamoli
2.	Number of villages	17
3.	Total population	10692
4.	Number of households	1851
5.	Average family size	5.8
6.	Sex ratio (Female : Male)	1079 : 1000
7.	Altitude (m)	
	Minimum	820
	Maximum	1850
8.	Percent electrified villages	100
9.	Percent school going children	95
10.	Land utilization pattern (ha)	1940
	Cultivable area	890 (46%)
	Forest area	491 (25%)
	Barren area	182 (9%)
	Pasture area	323 (17%)
	Homestead area	54 (3%)
11.	Monthly per capita foodgrain consumption (kg)	
	rice	7.4
	wheat	9.3
	pulses	2.0
	total foodgrain	18.7

12. Crop particulars

	Productivity (Quintal ha^{-1})	Area covered (ha)
Rabi crops (Nov-Mar)		
wheat	13.7	350
barley	12.2	15
mustard	6.1	3
masoor	6.6	5
Kharif crops (Jun-Nov)		
paddy	24.4	376
mandwa	16.3	324
sawan	17.3	54
maize	13.2	6

13. Daily fodder consumption per animal

	Stallfed (kg)	Grazing area (ha)
cow	19.9	138
calf	7.4	134
bullock	24.8	118
buffalo	32.4	-
goat	-	550
sheep	3.0	435

Chapter 4
Stress on woody biomass resources due to energy needs

Ajay Sharma, Rakesh Prasad
P Venkata Ramana
Veena Joshi

Chapter 4

STRESS ON WOODY BIOMASS RESOURCES DUE TO ENERGY NEEDS

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4 Stress on woody biomass resources due to energy needs

4.1 Introduction

It is estimated that more than 50% of the energy demand in rural parts of our country is met by woody biomass. In the recent past, expansion of the civil supply network of petroleum products, coal, electricity and LPG has reduced the percentage of households in urban areas using woody biomass for energy. But still, the situation has not changed much in villages scattered on the tough terrain of the Garhwal Himalaya. People extract woody biomass for their various needs from the stands in the vicinity of their habitats.

With the passage of time, the pressure due to the demands of an increasing population has reduced vegetation cover as well as altered consumption patterns. People have switched over to low quality fuel and fodder species, e.g., Banj (<u>Quercus incana</u>) leaves are fed to the animals and thinnings of fruit trees yield firewood. Moreover, the shrinking vegetation cover also leads to drying up of water-bodies and soil erosion. This stress has highlighted the need to plan for judicious use of biomass and to carefully work out the conservation strategies for natural woody biomass resources so as to retain their valuable contribution towards a sustainable environment.

The study area covered three micro-watersheds, namely Shorgad (Chamoli district), Chandrabhaga (Tehri district) and Irgad (Pauri district) in the Garhwal region of Central Himalaya. In these micro-watersheds we chose 6, 7 and 4 villages respectively. The climate of the region is sub-temperate to temperate. Most of the land is under mixed coniferous forests, dominated by Chir (<u>Pinus roxburghii</u>), Banj (<u>Quercus leucotrichophora</u>) (syn <u>Q. incana</u>), Kharik (<u>Celtis australis</u>), Timla (<u>Ficus roxburghii</u>), Burans (<u>Rhododendron orientalis</u>), Tun (<u>Cedrela toona</u>), Bheemal (<u>Grewia optira</u>), etc. Other associated species are Gurial (<u>Bahunia purpurea</u>), Chamchri (<u>Ficus gibbosa</u>), Sandan (<u>Ougenia orjeinensis</u>), Ainyaar (<u>Pieris ovalifolia</u>), Chinna (<u>Sapium insigne</u>), Genthi (<u>Boehmeria regulosa</u>), Piaman (<u>Syzygium cerasoides</u>), Karunda (<u>Carissa spinarum</u>), Ramna (<u>Acacia pinnata</u>), Tunga (<u>Rhus cotinus</u>), Semal (<u>Bombax ceiba</u>), Thundra (<u>Terminalia belerica</u>), Asaine (<u>T. tomentosa</u>), Akhrot (<u>Juglans regia</u>), Bakain (<u>Melia azedarach</u>), Kaiphal (<u>Myzrica nagi</u>), Amrud (<u>Sedium gujava</u>), Aam (<u>Mangifera indica</u>), Papaya (<u>Carica papaya</u>), Nimbu (<u>Citrus medica</u>), Anaar (<u>Punica granatum</u>) and Mola (<u>Pyrus patia</u>).

While carrying out the present study it was decided to compute the differences between the demand and supply of natural woody biomass resources in a few selected villages of each micro-watershed. Total woody biomass in village was enumerated to assess the maximum potential of biomass

system to provide photosynthates for various energy and non-energy end-uses. However, only the demand of biomass for energy uses was to be considered.

4.2 Methodology

4.2.1 Choice of stratum

The entire land in a village was stratified into three strata, namely homestead, agricultural land and village forest land. These strata were clearly differentiated in terms of vegetation cover, species-mix and access to public. Land allocated to various strata is well defined in Patwari's records as convertible barren land, agricultural land, village forest land and pasture land. However, no records were kept of homestead land. Based on the actual utilization of land, the land under various strata was identified and surveyed. While surveying, the local people were helpful in defining their homesteads and agricultural lands. All types of community land, namely village forest, barren and pasture lands were combined to form a single strata - forest land.

4.2.2 Choice of species

All timber, fuel, fodder and fruit species contribute to the total woody biomass of the village. In the selected villages of the study area, 113 woody species, listed in Appendix 4.1, were found. Among those, only one to six species in different villages could be classified as major species having significantly higher woody biomass as compared to others. To separate out these major species,

miscellaneous species were identified by determining the basal area under each species.

Basal area for individual species, in each village, was computed by using the formula:

$$B = \frac{G^2}{4\pi}$$

where B was basal area (m^2) and G was the girth (m) at breast height.

Total basal area is the aggregate of basal areas contributed by individual species in different strata. On the basis of the basal area in the selected villages, the species which:

a) contributed less than 3 percent of total basal area

b) were fruit species

c) were not lopped for either fuel or fodder

were clubbed together as miscellaneous species. Such a selection, based on basal area may rank a certain species as miscellaneous in one village and as major in another and vice-versa.

When site gets cleared, because of human activities or natural phenomenon, a natural succession to cover the site begins. Each year new species appear, some of which die out during successional stages giving way to new ones while others continue to stay for longer periods. Ecological succession is a continuous process till the climax-vegetation gets established. Various successional

stages merge giving rise to the presence of large number of species depending on altitude, aspect, slope, soil type and damage from human and cattle population. Usually, the dominant species, which are useful, disappear first from the ecological system. The surviving species are then used as fuel, though they are of inferior quality. To compute rates of growth for every species will involve too much time and money without any commensurate benefit.

By independently considering all the species contributing more than 3 percent of total basal area we avoided the problem of introducing a bias in identifying preferred species. All the fruit species were found to have negligible sustainable yield for energy end-uses and hence were also ranked as miscellaneous species. Often, fruit species like Aam, Amrud, Jamun, Chula, Apple, etc. had significantly high basal areas, but in lieu of their negligible sustainable fuel yield, these were classified as miscellaneous species. Species like Reetha, Harra, Behera, Akhrot, Kaphal and Karaunda were regarded as miscellaneous species as these also did not yield significant preferred fuel or fodder on a sustainable basis.

4.2.3 Measurements

Biomass comprises all forms of matter derived from biological activities, and is present either on the soil surface, or at various depths in water bodies. Total enumeration of all the trees which had attained a GBH of

20 cm assures a fair measurement of all the woody biomass. All the plants below this standard were excluded because of the negligible proportion of wood generated by them. Sometimes we excluded very big trees also (ranging from 4 to 9 times the average size) as they had some religious or sentimental value attached to them because of which they were never lopped or cut to provide fodder or wood. This is true of the trees standing in temples or other religious places.

All the trees were measured for their girth at breast height (GBH) with the help of a measuring tape. The height of five trees of each species in every village was measured with Abney's level. Heights measured in this manner in 17 villages yielded at least nine sets of five observations for each species. Regression equations for height were worked out based on those 45 readings observed for girth and height. Assuming a linear relationship between height and girth, the general form of the regression equation was:

$$H = a + b \times (G)$$

where H was height (m), G was GBH (m).

The coefficients in the regression equations that were obtained for various species are given in Appendix 4.2. Multiple determination coefficient (r^2) ranged from 0.72 to 0.96. Regression equations derived for the height of different species were not specific to any stratum or village, but were applicable to the entire study area.

Data pertaining to these two growth parameters were recorded for all the three stratum in each village. Miscellaneous species were selected for a village as a whole and not for individual stratum. After determining the miscellaneous species, the data for all other species was processed separately.

.2.4 Data compilation and analysis

The girth data collected for all the trees on various stratum in selected villages was arranged in different girth classes. Generally the range of girth classes was 0.2 m to 0.5 m, for most of the species and sometime extended to 0.6 m, also. Subject to different crop conditions, the number of girth classes varied from 3 to 11 from one village to another, even for the same species.

For the tree crop in various girth classes, height was calculated at mid points of each girth class, using the regression equation formulated earlier. Keeping in view the different relationships of volume with girth, diameter and height for various species, general equations for volume were:

$$\text{Volume} = a + b \times [(\text{Girth})^2 \times (\text{height})] \text{ and}$$

$$\text{Volume} = a + b \times [(\text{Diameter})^2 \times (\text{height})]$$

Standard regression equations for volume, depicted in Appendix 4.2, were taken from earlier published literature. For every girth-class, the girth at mid point and its corresponding calculated height were regarded as

the dimensions of a representative tree. The volume computed for each representative tree (by using the regression equation) was multiplied with the number of trees in that girth-class to calculate the gross volume in the girth-class. Aggregating the volume in each girth-class, the total volume for each species was obtained; and the sum of those volumes reflected the total volume under different stratum which again added up to the grand total volume of woody biomass in the village.

The annual sustainable yield was calculated over the total growing stock in the village by using Vonmontal's formula:

$$Y = \frac{2\ GS}{R}$$

where Y is sustainable yield, GS is growing stock (tonnes) and R is rotation (assumed 50 years).

Sustainable yield is comparable to the interest which one gets on capital invested in a fixed deposit. It is wise to consume only interest, specially when capital resources are scanty, but for deriving long term sustainable returns and for increasing growing stock it is advisable to consume only half of the annual interest or yield.

This formula suggested an annual sustainable yield of 4 percent of the total growing stock per year. But to overcome the damages due to:

a) biotic activities,

b) slow increment,

c) natural calamities, and

d) uncertain losses

in a mixed open woody biomass system of village, annual sustainable yield was modified to 2 percent of total growing stock for each village. Stress; defined as ratio of annual consumption to sustainable yield of natural resource, was computed separately for each village. Annual productivity in various strata is slightly on the lower side because sometime, the land classification data procured from secondary sources could not be verified due to conflicting data on land ownership. It was observed that generally the homestead constitutes a part of agricultural land. Moreover the village forest land generally includes not only the community land but also convertible barren land, ponds, wasteland and steep slopes. Standard conversions applied to the data are shown in Table 4.1. Woody biomass situation in different villages is depicted in the relevant graphs whereas the tables are appended in **Appendix 4.4**.

Table 4.1 Conversion factors

S.No.	
Wood (Volume)	
1.	1 tonne = 1.5 m^3
Land (Area)	
2.	1 acre = 20 nali

4.3 Results and discussion

4.3.1 Chamoli district

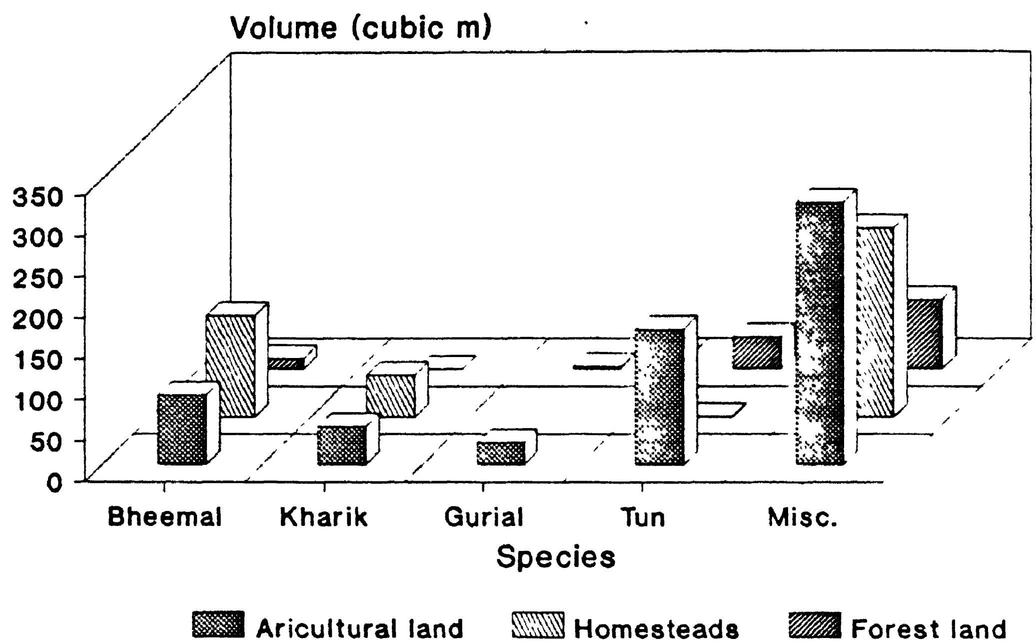
In this district, the composition of specie revealed that only 3 to 6 species, mostly fodder species, out of the 68 woody species, occupy more than 3 per cent of total basal area. This essentially reflects that prominent fuel species have already been removed and that now fuel is obtained from shrubs, loppings of timber trees, dead and diseased trees. At times, major species with more than 3 per cent of total basal area contributed only little woody biomass; probably, the size of trees had not increased enough for the last many years because of heavy loppings. Generally, 'Bheemal', 'Kharik', 'Banj' and 'Burans' have dominated the area but occasionally 'Tun' and 'Ainyaar' are also commonly found. The major woody biomass share, in every stratum, came from miscellaneous species (e.g. fruits) which are not preferred for fuel or fodder. It is important to note that in the villages where woody biomass was chiefly produced on village forest land, the sustainable yield was higher than in villages where woody biomass was chiefly produced on agricultural land. However, such villages are few. The almost complete removal of preferred fuel and fodder species led to higher density of miscellaneous species, specially on village forest land. This implied that a large portion of even sustainable yield was not available for energy purposes. The total growing stock was observed to be maximum in Ghimtoli village (3295.2 tonnes) whereas Chopra

village recorded the minimum (792.5 tonnes). The annual sustainable yields were 65.9 tonnes and 15.9 tonnes respectively. Village forest land was much less than total agricultural land in all but one village. Generally, the share of woody biomass generated on homesteads was lower than that of the other two strata. Young crops, of all species, contributed the most to biomass production because of the removal of older trees for construction and timber. Growing stock in villages is young and immature, besides being mixed, uneven-aged and open.

Chopra

The village is situated about 3 km from Silli, 14 km from Rudarprayag on the Rudarprayag-Kedarnath road. It supports 40 families on 481.5 ha of land. The available woody biomass is 792.5 tonnes, which was expected to yield 31.7 tonnes wood per annum, out of which the sustainable yield was found to be 15.9 tonnes (Figure 4.1). Miscellaneous species contributed 53.2 per cent of the total yield, whereas among the major species 'Bheemal' and 'Tun' contributed 18.7 and 17.30 per cent respectively. However, 'Kharik' and 'Gurial' also contributed 8.3 and 2.6 per cent of the total biomass respectively. 'Bheemal', 'Kharik' and 'Tun' contributed a major share, probably because these species were rated as second class timber but as first class fodder, which essentially encouraged lopping of leaves or branches for fuel & fodder and not the harvesting of the entire tree.

Fig 4.1 Biomass estimate:
Chopra



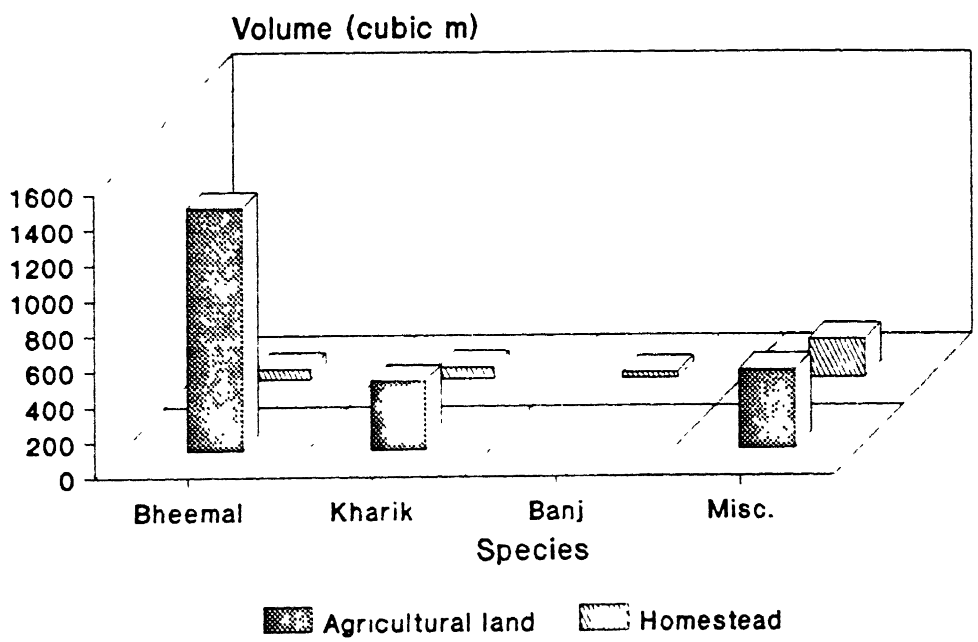
Homesteads contributed about one-third of the total wood production probably because of large number of fruit trees as well as other species which yield neither fuel nor fodder and are harvested rarely. The maximum woody biomass was derived from agricultural land (54.1 per cent) whereas homestead and village forest land contributed 34.1 and 11.8 per cent respectively. Woody biomass from agricultural land was very thinly distributed to yield 0.5 tonne ha^{-1} per annum at the most, as compared to 1.1 tonne ha^{-1} per annum from village forest land. Only a small amount of woody biomass was generated on community forest land because of very little land under this stratum. The low annual productivity on agricultural land can be attributed to rapid harvest of bigger trees for

timber purposes in the recent past. Harvesting timber wood from community land involves long chain of formalities and government authorities generally do not allow the same.

Gadil

The distribution of woody biomass is shown in Figure 4.2 and Appendix 4.4. Results revealed that in spite of being the smallest village (22.34 ha) and being devoid of village forest land, Gadil has a fairly good quantity of woody biomass growing on its lands, i.e. 1726.8 tonnes. In order to support 27 families, the growing stock yields a sustainable yield of 34.5 tonnes per annum. In the

Fig 4.2 Biomass estimate : Gadil



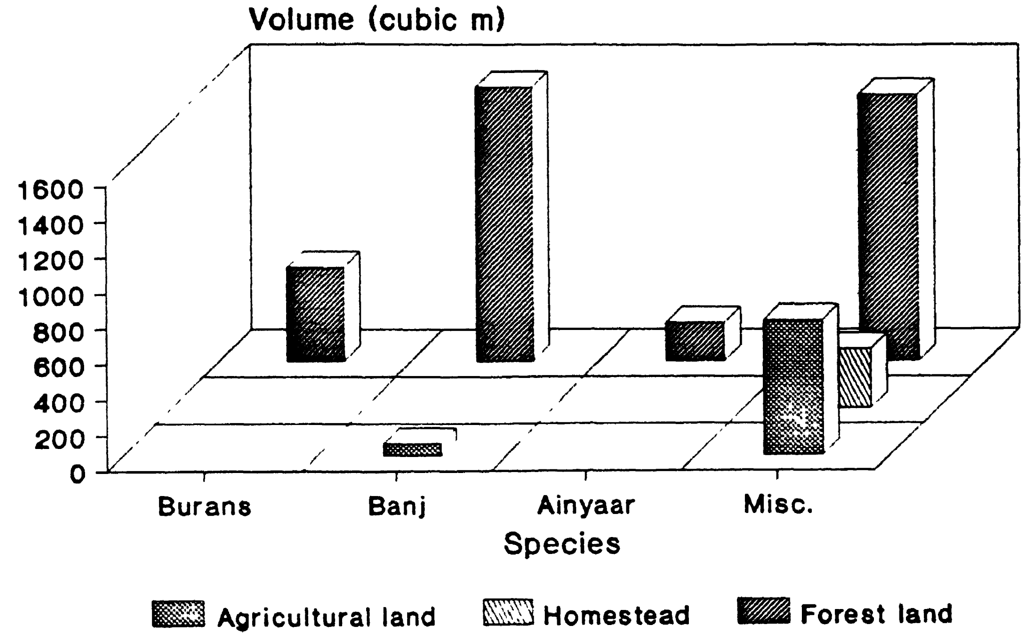
absence of village or community forest land, agricultural land was the main source of woody biomass and it contributed 85.1 per cent of the growing stock while the remaining 14.9 per cent wood grew on homesteads. Woody growing stock present on agricultural land was dense enough to produce 1.5 tonnes ha^{-1} per annum of biomass. This productivity of agricultural land is higher than that in all but one of the villages.

The composition of species reflected that 'Bheemal', 'Kharik' and ' Banj' are the major species. Miscellaneous species, generally fruit species gathered significant amounts of woody biomass, but the highest biomass is generated by 'Bheemal'. 'Bheemal' and 'Kharik' provide fodder and hence are rarely felled. As a consequence, a large number of big trees grow profusely, specially on agricultural land. The comparatively less contribution of miscellaneous species can be ascribed to the removal of second and even third rated timber and fuel species in the absence of preferred species. The major share of growing stock and sustainable yield came from fodder species. Thus, for energy and construction purposes, people largely depend on the woody resources in the vicinity of the village.

Ghimtoli

The perusal of data pertaining to woody biomass production in Ghimtoli village, shown in **Figure 4.3** and **Appendix 4.4**, reveals that 104.0 ha of total village land had a growing

Fig 4.3 Biomass estimate : Ghimtoli



stock of 3295.2 tonnes. Woody biomass was generally present as miscellaneous species, i.e. 52.5 per cent of total woody biomass was produced by these species. However, 'Banj' alone contributed 32.5 per cent; most of which was found on village forest land. 'Burans' and 'Ainyaar' were the other major species which provided 10.6 and 4.4 per cent of woody biomass respectively. The significantly higher woody biomass produced in 'Banj' may be ascribed to abnormally higher number of trees in almost all the girth classes which were lopped for fodder and were rarely felled. 'Banj' possesses a strong root system.

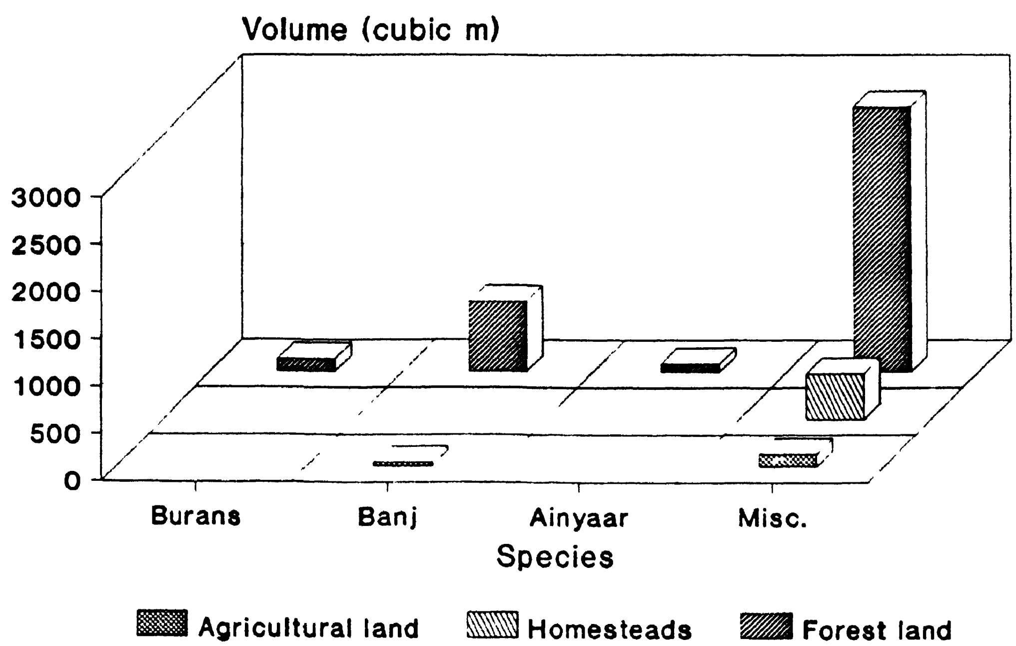
In each of the stratum, miscellaneous species dominated biomass production. At homestead none of the species occupied more than 3 per cent of basal area, whereas on agricultural land 'Banj' was the only major species.

Dense woody crop on village forest land contributed 76.3 per cent of biomass in comparison to agricultural land and homestead which contributed 16.9 and 6.8 per cent biomass respectively. Village forest land is expected to produce the highest annual sustainable yield of 3.1 tonnes of woody biomass per hectare. However, total sustainable yield of 65.9 tonnes per year is expected in the village from its own resources; although a major portion is derived from miscellaneous species.

<u>Kanda</u>

Data depicted in **Figure 4.4** reflects almost a similar situation to that of village Ghimtoli, discussed earlier.

Fig 4.4 Biomass estimate : Kanda



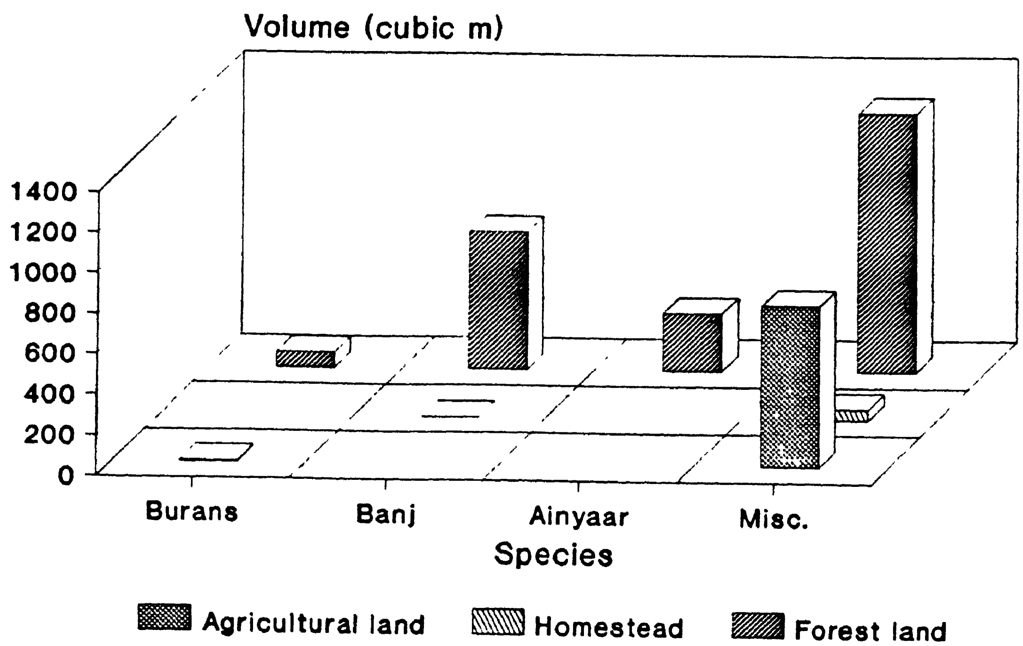
This small village supports a growing stock of 2940.1 tonne on 43.74 ha of land and has 35 families. 'Burans', 'Banj' and 'Ainyaar' occupied more than 3 per cent of total basal area. The remaining species, clubbed as miscellaneous, accounted for 77.3 per cent of total woody biomass. However, the major species, 'Burans', 'Banj' and 'Ainyaar' contribute 3.1, 17.8 and 2.1 per cent to the biomass, respectively. The greater biomass contributed by miscellaneous species can he ascribed to the removal of preferred species for energy and non-energy uses.

Among strata, village forest land had a fairly good canopy contributing 85.1 per cent to the biomass as compared to 10.9 per cent of homestead and 4.0 per cent of agricultural land. Village forest was expected to yield 2.6 tonnes ha^{-1} per annum whereas the productivity from agricultural land was as low as 0.3 tonnes ha^{-1} per annum. A total sustainable yield of 58.8 tonnes per annum was mainly contributed by village forest, because homesteads were generally occupied by fruit trees and agricultural land shared very little. Low productivity of agricultural land was due to removal of excess wood; which was not available from community land specially for non-energy uses, e.g. construction, funerals, etc.

Kyuri

Reflecting the similar situation as that of Ghimtoli and Kanda, in this village also woody biomass was distributed chiefly among miscellaneous species. Once again `Banj', `Burans' and `Ainyaar' were the major species. This was the largest village spread over 264.4 ha land; supporting 137 households in the absence of good growing stock. Biomass gathered from miscellaneous species was 66.7 per cent, however, `Burans', `Banj' and `Ainyaar' contributed 2.6, 21.5 and 9.0 per cent respectively (Figure 4.5). Although `Burans' and `Banj' provided significant biomass on agricultural lands and homesteads respectively, the larger portion of major species was present on village forest land. Extinction of preferred fuel and timber

Fig 4.5 Biomass estimate : Kyuri



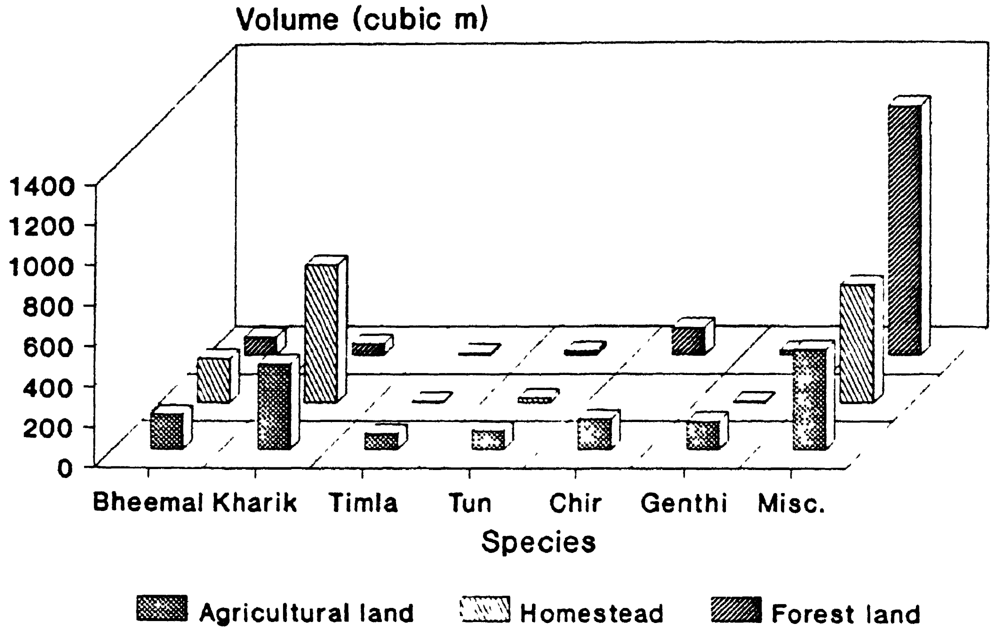
species can be attributed to increasing demand of wood for energy and non-energy uses. Village forest land produced the maximum biomass (73.2 per cent), followed by agricultural land (25.2 per cent) and then homestead (1.58 per cent). The total growing stock was 2109.3 tonnes bearing a sustainable yield of 42.2 tonnes per year. However, thin woody crop scattered over agricultural and forest land yielded 0.1 tonnes and 0.7 tonnes ha^{-1} per year, respectively.

Saur Bhatgaon

This village has 92.7 ha of land for 128 families. The growing stock was found to be 3078.3 tonnes producing an annual sustainable yield of 61.6 tonnes. The mix of species in the village revealed a satisfactory situation where six species, generally preferred for fuel, fodder and timber, have been classified as major species. Besides 49.7 per cent biomass produced by miscellaneous species, 'Bheemal' and 'Kharik' produced 10.4 and 25.1 per cent, respectively, of woody biomass. However, 'Timla', 'Tun', 'Chir' and ' Genthi' produced 2.1, 2.9, 6.1 and 3.7 per cent of total biomass, respectively (Figure 4.6).

The reasonably higher production by prominent fodder and timber species in this village can be ascribed to the practice of loppings for fodder rather than felling, in spite of a large population size.

Fig 4.6 Biomass Estimate :
Saur Bhatgaon



Biomass production among various strata varied only slightly, as agricultural land, homestead and forest land produce 33.6, 32.6 and 33.8 per cent of total woody biomass. Agricultural land yielded 0.3 tonnes of biomass per year per hectare, whereas village forest land generated 1.1 tonnes per year per hectare.

4.3.2 Tehri

Flora in this district, is enriched by 110 woody species, among which 11 species occupy more than 3 per cent of total basal area in different villages. Besides the number of major species, the composition of species also reflects a marked difference with that in Chamoli as 'Paiyan', 'Sal', 'Khinna', 'Genthi' and 'Timla' have a marked presence. Among these species, 'Bheemal' was the

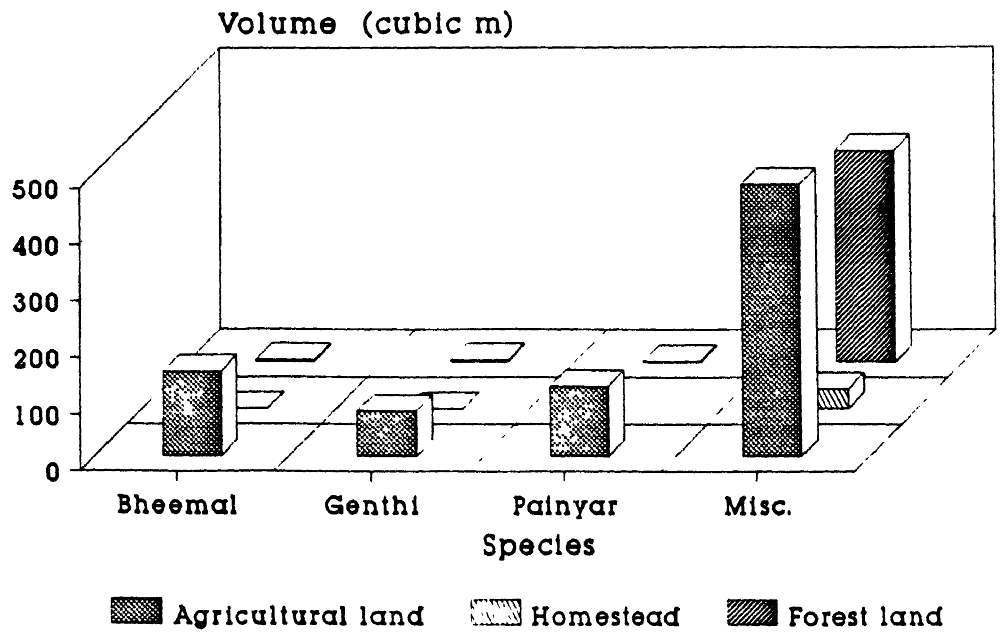
only major species which was present on a significantly larger portion of basal area in almost all the villages. The major share of woody biomass, varying between 56 to 91 per cent, was contributed by miscellaneous species. The composition of species revealed an almost complete removal of preferred fuel, timber and fodder species, alike Chamoli district. Moreover, on the same lines, pressure was gradually increasing on less preferred and low utility species, which are classified as major species in all the villages. Young growing stock was mixed, uneven-aged and open, in every village. Generally, the sustainable yield was considerably higher in the villages where wood biomass was chiefly produced on village forest land as compared to villages deriving a larger share from agricultural land. The highest total growing stock (19995.4 tonnes) was recorded in Daggar village, whereas the lowest (831.87 tonne) was observed in village Siur, which revealed an annual sustainable yield of 399.9 and 16.6 tonnes, respectively. Homesteads produced very little woody biomass probably because of very small landholdings under this stratum. Generally, village forest land was distinctly more than agricultural land, in all the villages unlike Chamoli.

Siur

This is a fairly large village (107.9 ha), supporting a large population (44 families). Biomass yield was 831.9 tonnes. Miscellaneous species provide 71.2 per cent

of the wood. However, the major species 'Bheemal', 'Genthi' and 'Paiyaan' contributed 12.2, 6.7 and 9.9 per cent of the total biomass, probably because these are preferably lopped for fodder than felled for timber or poles. Homesteads contributed hardly 3 per cent of woody biomass, whereas forest lands yielded 30.6 per cent and agricultural lands contributed the highest (66.5 per cent) to total woody biomass (Figure 4.7). Woody biomass on village forest land was very scanty and yielded only 0.07 tonnes ha^{-1} per annum as against 0.3 tonnes ha^{-1} per annum on agricultural land. The contrasting low productivity of forest land can be ascribed to the tendency to harvest common property resources at the earliest, to acquire a greater share of biomass, specially for construction and other non-energy uses.

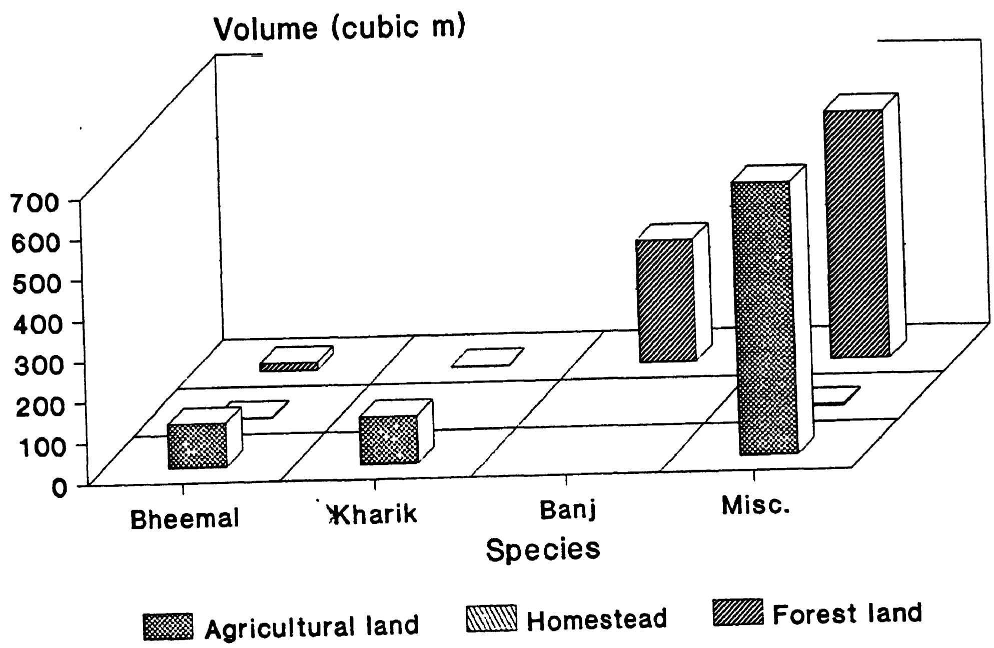
Fig 4.7 Biomass estimate : Siur



Guad

This village has 103.41 ha and 19 families. Results show that 1218.5 tonne woody biomass is produced. The biomass distribution is shown in Figure 4.8. Growing stock produced a sustainable yield of 24.4 tonnes per annum. Woody biomass growing on agricultural land generated 0.3 tonnes ha^{-1} per annum, whereas village forest land produced 0.2 tonnes ha^{-1} per annum. The total production on both those strata was almost identical, but because of a larger area and rapid depletion of common property resources, the productivity from village forest land was low. Homestead contributed very little (0.4 per cent) as

Fig 4.8 Biomass estimate : Guad

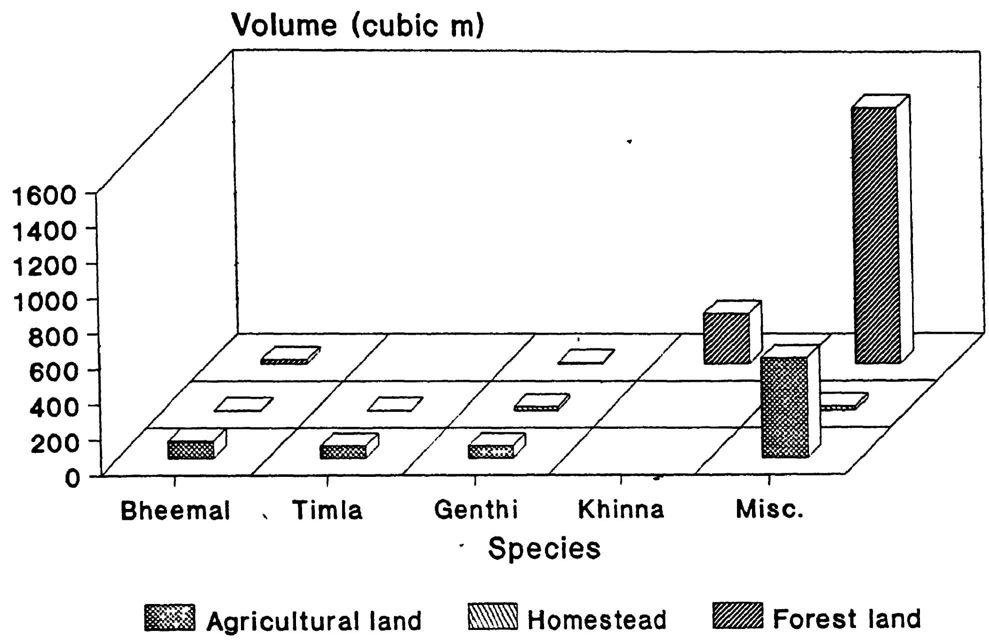


compared to agricultural land (48.9 per cent) and village forest land (50.8 per cent). The composition of species reflected that only 'Bheemal', 'Kharik' and 'Banj' were the major species contributing 7.0, 6.4 and 16.4 per cent of woody biomass, respectively. However, miscellaneous species provided the largest share (70.3 per cent) and dominated all the three stratum. Considerable biomass gathered on fodder species i.e. 'Bheemal', 'Banj' and 'Kharik' was probably due to the removal of preferred timber and fuel species for energy and non-energy uses. The major share of growing stock and sustainable yield was contributed by fodder species. Therefore, for energy and construction purposes people largely depend on the woody resources in the vicinity of the village.

<u>Tallai</u>

The perusal of data pertaining to woody biomass production in Tallai village, shown in Figure 4.9, reveals that 39.7 ha of the total village land had a growing stock of 1751.7 tonnes to sustain 35 families. Woody biomass was chiefly obtained from miscellaneous species (77.7 per cent), however, 'Bheemal', 'Timla', 'Genthi' and 'Khinna' provided 4.8, 2.7, 3.9 and 10.9 per cent respectively. Mixed, uneven-aged and young growing stock, reflected a greater share of woody biomass from miscellaneous species on village forest land. This can be ascribed to the removal of useful and large sized species thus leaving behind only less useful miscellaneous species.

Fig 4.9 Biomass estimate : Tallai



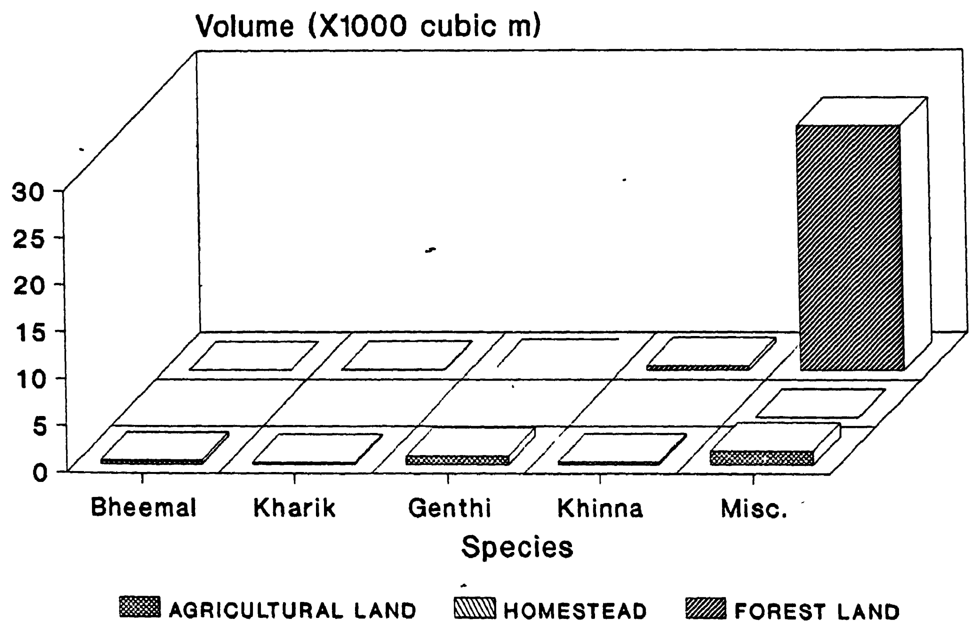
In each of the stratum, miscellaneous species dominated biomass production. Village forest land and agricultural land yielded 67.5 and 30.5 per cent, however, homestead produced only 2.0 per cent of woody biomass. An annual sustainable yield of 35 tonnes wood was gathered in the village. Agricultural land and village forest land provided 0.6 and 1.0 tonne wood per hectare per annum, respectively, although a major share was derived from miscellaneous species.

<u>Daggar</u>

Data shown in **Figure 4.10** and **Appendix 4.4** for the village reflects almost a similar situation to that of village Tallai, discussed earlier. This village supports a growing stock of 19995.4 tonnes on 111.7 ha of land for 45

families to share. All major, species i.e. 'Bheemal', 'Kharik', 'Genthi' and 'Khinna' contributed 1.5, 0.6, 3.8 and 2.5 per cent, whereas miscellaneous species contributed 91.6 per cent of woody biomass. Greater biomass obtained from miscellaneous species can be ascribed to the removal of preferred species for energy and non-energy uses. Among strata, village forest land had fairly good stock to contribute 89.1 per cent of woody stock, followed by 10.7 per cent on agricultural land and 0.2 per cent on homestead. Village forest land was expected to yield 5.0 tonnes ha^{-1} per annum whereas productivity from agricultural land was 1.0 tonnes ha^{-1} per annum.

Fig 4.10 Biomass estimate : Daggar

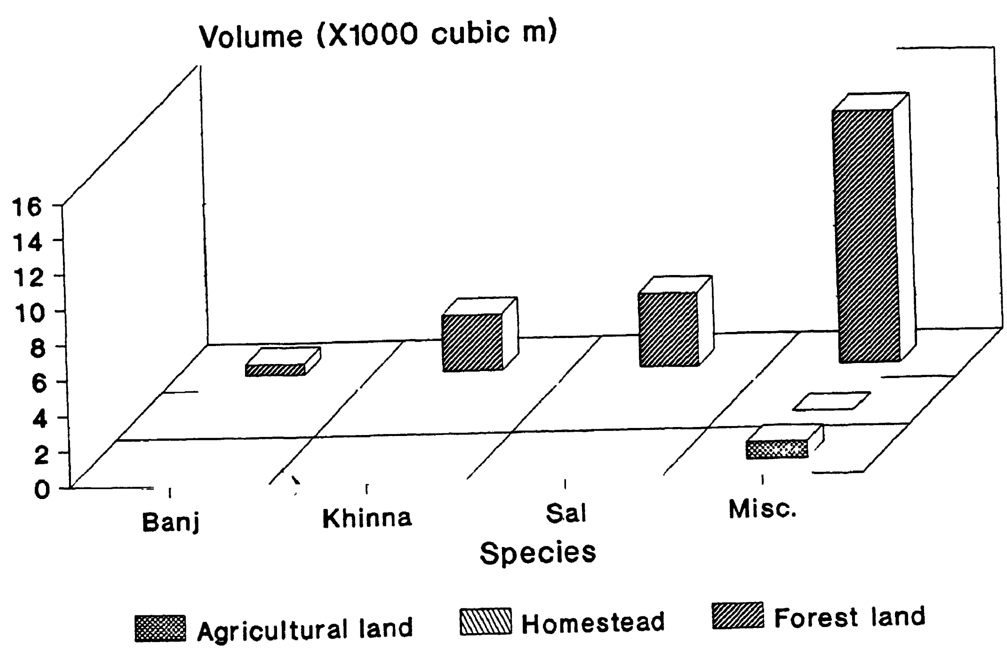


A total sustainable yield of 399.9 tonnes per year was mainly contributed by the village forest and that too from miscellaneous species. This situation results in consumption of low utility, non-preferred fuel, and timber species.

<u>Soni</u>

Village Soni has a good growing stock of 15518.04 tonnes spread over 145.8 ha land for 50 families to share. Only 3 species, i.e. 'Banj', 'Khinna' and 'Sal' covered more than 3 per cent of basal area and contributed 2.6, 13.7 and 17.9 per cent of total woody biomass primarily from the village forest land (Figure 4.11). The largest share

Fig 4.11 Biomass estimate : Soni

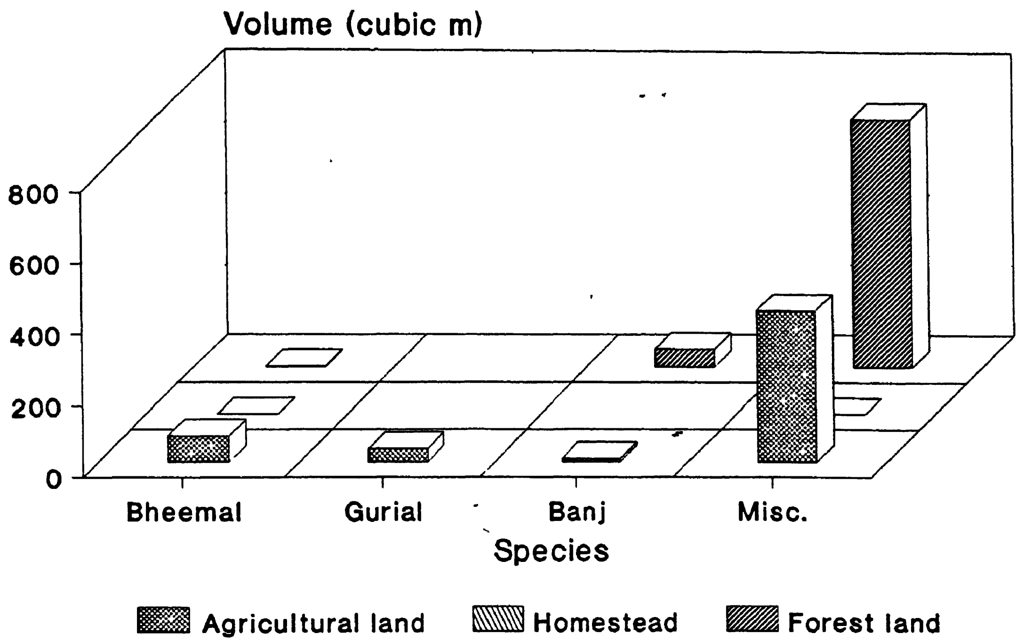


of woody biomass came from the village forest land (95.8 per cent) followed by agricultural land (4.1 per cent) and homestead (0.1 per cent). The growing stock had sustainable yield of 310.36 tonnes per year and is chiefly contributed by village forest land. Village forest land was expected to produce 2.5 tonnes of wood per hectare per annum, whereas agricultural land yielded only 0.5 tonnes per ha per annum. The low productivity of agricultural land was due to very little growing stock in the stratum.

Baggar

This is the smallest village (31.1 ha) with 10 families and 863.55 tonnes of woody biomass. This growing stock yielded 1727 tonnes of wood per year for consumption. A major portion of which was derived from miscellaneous species (87 per cent). However, major species, 'Bheemal', 'Gurial' and 'Banj' contributed 5.7, 2.8 and 4.4 per cent. A significant amount of woody biomass was obtained from these species because these are always lopped for leaves and never felled for wood (Figure 4.12). Although maximum biomass (58.1 per cent) was generated on village forest land, agricultural land produced 41.8 per cent and almost negligible (0.01 per cent) wood was produced on homestead. Agricultural land bears a sustainable yield of 0.7 tonnes per ha per year whereas forest land produced 0.5 tonnes per ha per year. Growing stock and sustainable yield derived their major share from miscellaneous species. Hence, for energy and non-energy uses, woody resources in the vicinity of the village are tapped.

Fig 4.12 Biomass estimate :
Baggar



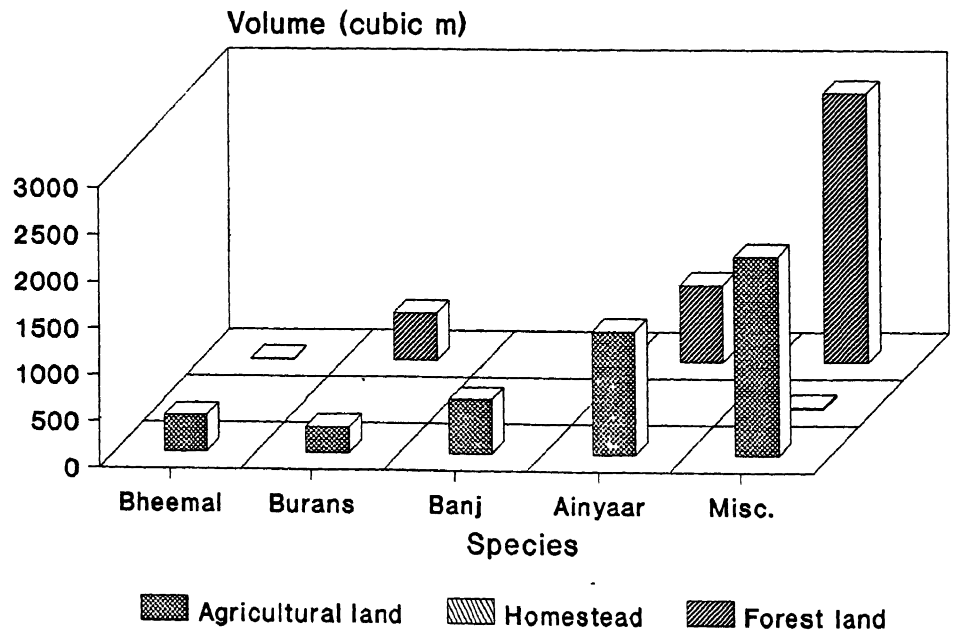
Kasmoli

This village has 55 families on 258.3 ha land with 5925.4 tonnes of woody growing stock. The mix of species in the village revealed that preferred fodder species, i.e. 'Bheemal', 'Burans' and 'Banj' and 'Ainyaar' dominated biomass production contributing 4.5, 8.7, 6.5 and 24 per cent of woody biomass respectively. However, a major share (56.3 per cent) was generated by miscellaneous species (Figure 4.13). Miscellaneous species dominated biomass production in all the three stratum.

Homestead produced the lowest biomass (0.22 per cent) whereas village forest land generated 47.14 per cent. The highest biomass (62.4 per cent) was produced on agricultural land. The reasonably higher production by

miscellaneous species can be ascribed to the removal of preferred species for energy and non-energy uses by increasing human and livestock population. Agricultural land yielded 0.7 tonnes of woody biomass per hectare per year, whereas village forest land generated 0.3 tonnes per hectare per year.

Fig 4.13 Biomass estimate : Kasmoli



5.3 Pauri

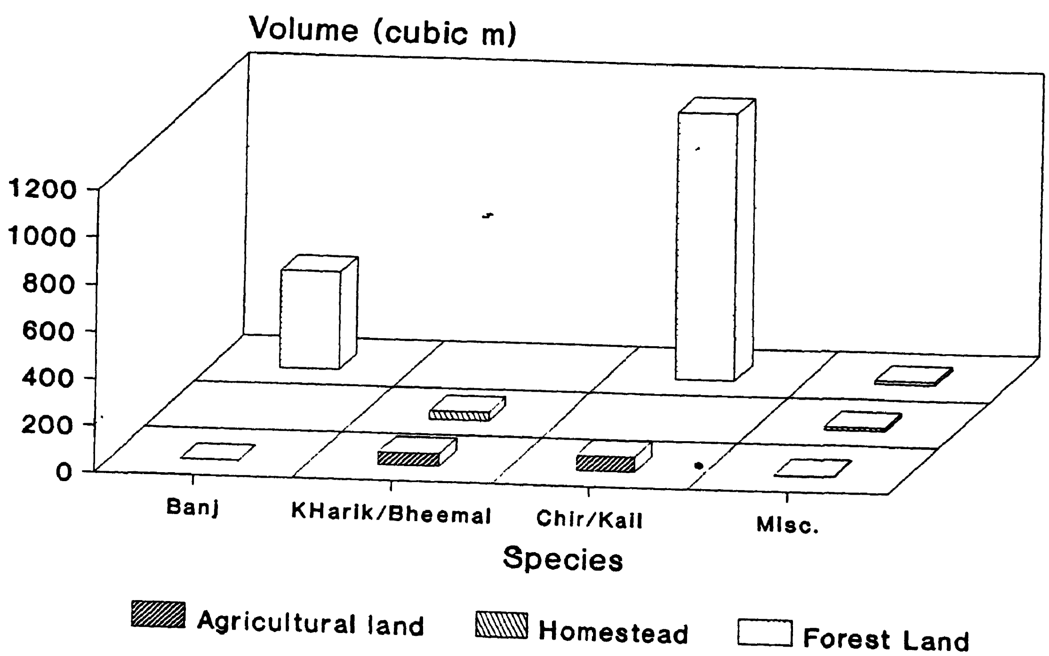
The forest communities of Pauri Garhwal extend between dry and moist temperate regions. The major species found in the district are: 'Banj', 'Chir', 'Kail', 'Deoadar', etc. In the villages in the study area, out of 27 woody species, only 4 species occupy more than 3 per cent of the total basal area. The prominent species like 'Chir', 'Kail', 'Banj' have been removed from few village forest lands for fuel, fodder timber and agriculture. Generally, 'Kharik' and 'Bheemal' have dominated agricultural land and homestead, whereas 'Banj', 'Chir' have contributed the highest (60% to 80%) to the total woody biomass. But at higher altitudes, 'Banj' also contributed between 20% to 80% to the total biomass. The sustainable yield was much higher on village forest land than on agricultural land and homestead. This was due to the dominance of pine trees in the forest surrounding the habitations. The maximum total growing stock (1158 tonnes) was observed in Bhimalli-malli village, whereas the minimum (916.5 tonnes) was recorded in Bhainswara village and reflected an annual sustainable yield of 23.2 and 18.3 tonnes respectively. The village forest land was considerably less than the total agricultural land, in all the villages studied. Generally, the woody biomass was contributed by prominent timber species in all the stratum, in every village. However, fodder species also gathered a good amount of biomass. This reflects that for various energy and non-energy uses, fodder species as well as second graded

timber species have been excessively harvested. The low productivity under homesteads can be attributed to the unavailability of land, as well as very little basal area generated under trees in this stratum.

Bhimalli-malli

The village is about 2 km from Ghorikhal, 12 km from Pauri on the Pauri-Kotdwar road. It supports 50 families on 33.2 ha of land. The total woody biomass was found to be 1778.47 tonnes, which generated an annual sustainable yield 19.30 tonnes. `Chir' and `Kail' provided 69 per cent of the total yield. However, other major species, i.e. `Banj', `Kharik' and `Bheemal' contributed 24 and 5.2 per cent to the total biomass respectively (**Figure 4.14**).

Fig 4.14 Biomass estimate : Bhimalli-malli



Miscellaneous species contributed only 2 per cent to the woody biomass. The results reveal that, primarily, woody biomass was gathered from prominent timber and fodder species, probably because of the practices of lopping and not harvesting these species.

Village forest land contributed about 90 per cent to the total woody biomass, probably because of the large number of big trees available on the land which and are under control of the 'van panchayats'.

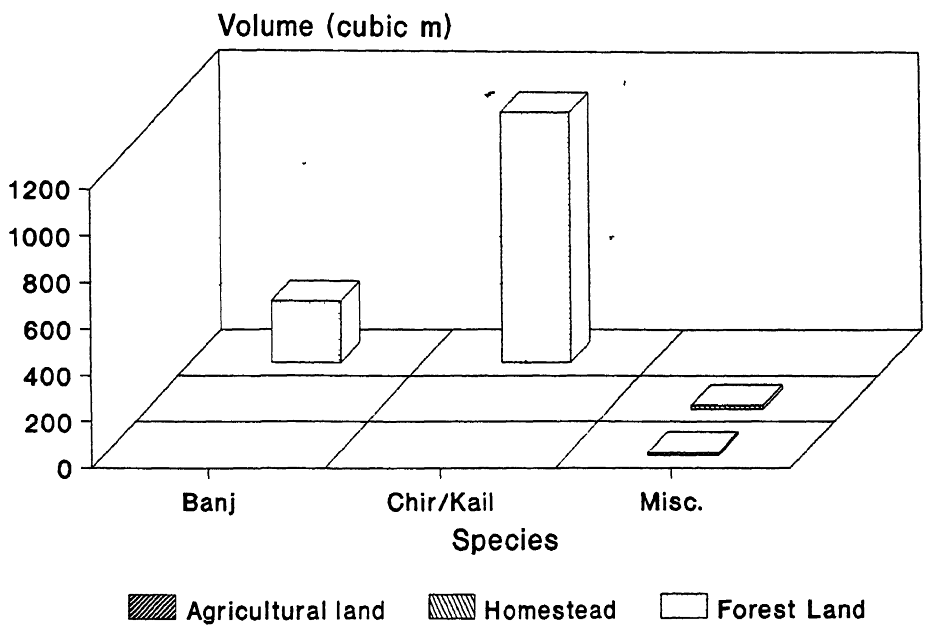
Homestead and agriculture land contributed 2.9 per cent and 7.3 per cent respectively. The low annual productivity on agriculture land can be attributed to the rapid harvest of bigger trees for timber, construction and fodder purpose.

<u>Agrora</u>

Data shown in **Figure 4.15** and **Appendix 4.4** for the village reflects almost the similar situation to Bhimalli-malli, discussed earlier. This village supports a growing stock of 1059.32 tonnes on 105.2 ha of land for 48 families to share. The major species 'Kharik' and 'Chir' contributed 6.13 and 89 per cent, whereas miscellaneous species contributed 5.2 per cent to the total woody biomass. Among the strata, village forest land had a fairly good stock to contribute 82.6 per cent, followed by 13.0 per cent on agricultural land and 4.4 per cent on homestead. Village forest land was expected to yield 1.2 tonnes ha^{-1} per annum, whereas productivity from agricultural land was 0.07 tonnes ha^{-1} per annum.

and agricultural land. The major share of growing stock and sustainable yield was contributed by timber species, which essentially encourages people to consume less preferred fuel and fodder species for energy & non-energy uses.

Fig 4.16 Biomass estimate : Bhainsarau

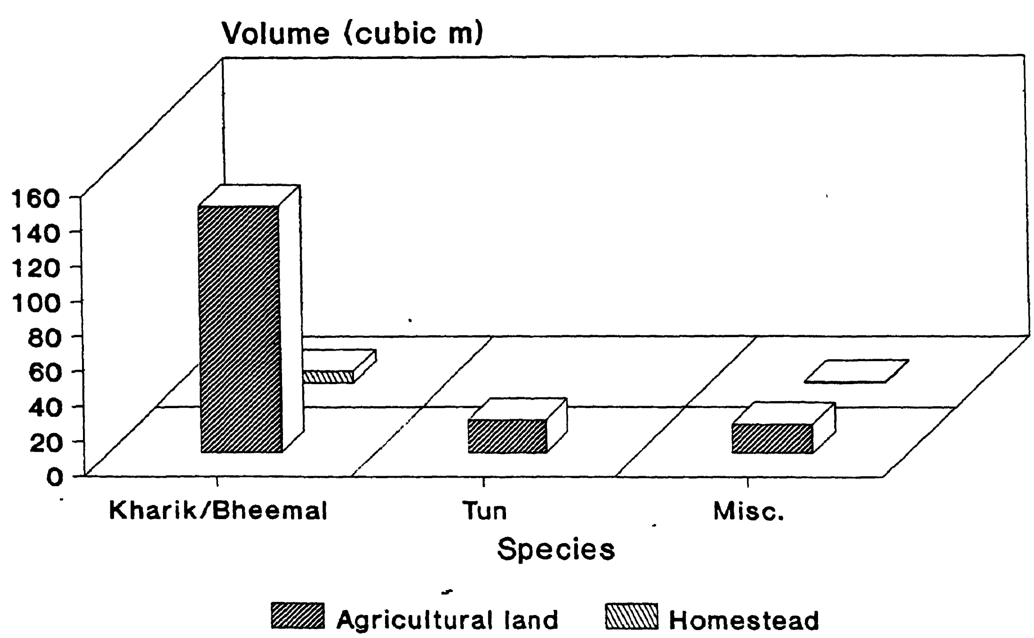


<u>Ghiri</u>

This large village supports 60 families on 61.7 ha. The total stock of woody biomass was 127.7 t, to which miscellaneous species contributed 17 per cent. However, Kharik contributed 80.6 per cent. The share of woody biomass from village forest land was nil, probably because the stratum was devoid of woody vegetations. Homestead contributed only 4 per cent to the woody biomass, whereas agriculture land contributed 96 per cent (Figure 4.17).

The woody biomass productivity was significantly higher on agricultural land i.e. 2.3 t ha^{-1} per annum, as compared to 0.1 t ha^{-1} per year on homestead. Lack of production from village forest land may force people to further stress the agricultural land for wood to satisfy their daily demands. A higher contribution was obtained from 'Kharik' which was preferred for fodder rather than for fuel purposes.

Fig 4.17 Biomass estimate : Ghiri



4.3.4 Stress on biomass resources

Stress computed for all the villages, shown in **Table 4.2**, revealed that generally people consumed 2 to 5 times the sustainable yield from the growing stock within the village boundary. This essentially reflected an unwise rapid rate of removal of growing stock itself, besides the sustainable yield. This trend of felling may explain the low productivity of common lands in general and removal of preferred fuel and fodder species in particular. Perusal of data reveals that the supply from woody biomass was not sufficient to meet the local energy demand, in most of the villages. In some of the villages, stress had attained very high values which can probably be explained by the following reasons:

1. Total production in those villages was generally lower than in other villages.
2. Productivity of village forest land or common land was low.
3. Biomass had been enumerated within the village boundary only, whereas people may have had access to government land and neighbouring villages also. So sustainable yield was on lower side.
4. Our methodology excluded shrubs and bushes as we enumerated only the growing stock which has a girth above 20 cm at breast height.
5. Shrubs had to be excluded as people did not allow their destructive sampling.

Generally, stress was higher in the village where community land, i.e. village forest land, had been excessively harvested. The situation was almost irreversible in the villages where prominent timber, fuel and fodder species had already been removed or reduced to occupy less than 3 per cent of basal area. Higher productivity on agricultural land, where trees were generally scattered along bunds and contours, as compared to village forest land essentially reflected poor woody crop. However, on the other hand its lower productivity might not reflect over-exploitation of agricultural land. On the contrary, it might reveal the presence of a fairly good woody stock in the vicinity, which in case of over-exploitation should be devoid of preferred timber, fuel and fodder species, as was prominent in the villages under study.

Table 4.2 Stress on biomass resources

S.No.	Name of village	Annual Sustainable Yield (A) (tonnes)	Annual Total Consumption (B) (tonnes)	Stress (B/A)
Chamoli				
1.	Ghimtoli	65.9	137.6	2.1
2.	Kanda	58.8	230.9	3.9
3.	Kyuri	42.2	604.7	14.3
4.	Gadil	34.5	93.1	2.7
5.	Saur Bhatgaon	61.6	444.6	7.2
6.	Chopra	15.9	290.0	18.3
Tehri				
1.	Kasmoli	118.5	408.8	3.5
2.	Siur	16.6	304.4	18.3
3.	Guad	24.4	81.1	3.3
4.	Saur	310.4	401.5	1.3
5.	Baggar	17.3	74.8	4.3
6.	Daggar	399.9	253.3	0.6
7.	Tallai	35.0	193.6	5.5
Pauri				
1.	Agrora	20.6	89.4	4.3
2.	Ghiri	0.85	114.8	135.1
3.	Bhainswara	16.3	54.4	3.3
4.	Bhimalli-malli	19.3	90.3	4.7

4.4 Recommendations for further study

An accurate assessment and careful planning of biomass resources is essential, because in a society using "non-commercial energy sources" (to meet energy as well as non-energy uses) to satisfy more than 75 per cent of energy requirements, a definite relationship between rural energy and sustainable development cannot be denied.

In the current study, the following shortcomings were observed:

1. Secondary data, which were regarded a strong baseline, were not satisfactory, primarily because these were not updated regularly for every village. Data from revenue records for land distribution under various uses, namely habitat, agriculture, forest, barren and wasteland, could not be verified in the field properly. This could slightly deviate the estimates for productivity. Area recorded under homestead was far below actuals, as every time a new house was constructed there was a corresponding reduction of agricultural land or private barren lands. Moreover encroachments over government forest land or village panchayat land were not depicted specially with regard to any change in village boundaries.
2. People used wood resources regardless of its legal status, i.e. their own village, neighbouring village or even conventional forest. So the assessment of woody biomass within the village boundary only, would not estimate the actual biomass being harvested. As per the convenience and availability of time, people might alter the limit of area for wood extraction. Every village had a defined area for biomass system which may extend over to few kilometers. Prior to biomass assessment in a village, its biomass system boundary should be identified and defined.

3. Use of cow-dung and agricultural crop-residues for energy and non-energy end-uses varied from region to region. International or national standards and ratios applied for the estimate of their production were outdated; because of variations in species, varieties, altitude, environment and nutrition level, in different villages. It is advised to develop accurate local standards and ratios while conducting primary survey in field.

4. The present methodology enumerated only the biomass above a certain defined girth at breast height (say 20 cm). This overlooked shrubs and young trees which were felled on priority because of their easy transportation, early drying and convenience while burning. In subsequent surveys the point of measurement can be brought down to to 50 cm above ground instead of lowest height (137 cm). Quadrate and sampling methods should be applied for the estimation of not only the young group or under-growth but also for the woody stock standing over conventional forest land. From the secondary data available with forest department growing stock in terms of volume could not be determined specially at village level, which emphasized the need to deal with forest secondary data more carefully as well as to crosscheck by field inventory.

5. To observe the linkages between consumption pattern and species-mix in the system, it was required to define the species and type of the biomass being actually used. It would highlight the need of proper technologies to deal with young crop and undergrowth. It would divert attention towards the species which were extensively harvested and reduced to occupy relatively low basal area. Most of the time major species, which occupied significantly higher basal area, were not preferred for energy or non-energy end-uses. The major share of sustainable woody biomass was derived from miscellaneous species and only its small fraction was used for consumption. In such a situation, careful study of type of biomass and species under use could help in estimating the effective sustainable yield fairly accurately.

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Appendix 4.1 Species bearing woody biomass

Local name		Botanical name
1.	Aam	- *Man:ifera indica*
2.	Aaru	- *Prunus •ersica*
3.	Akhrot	- *Juglans regia*
4.	Amaltash	- *Cassia fistula*
5.	Amrud	- *Psidium guyava*
6.	Amwla	- *Emblica officinallis*
7.	Anaar	- *Punica :ranatum*
8.	Asaine	- *Terminalia tomentosa*
9.	Banj	- *Quercus leucotricophora*
10.	Bakharu	- *Lonicera sp.*
11.	Bans	- *Dendrocalamus strictus*
12.	Bar	- *Ficus bengalensis*
13.	Baryan	- *Zizyphus sativa*
14.	Bedu	- *Salix spp.*
15.	Bel	- *Aegle marmelos*
16.	Belkar	- *Prinsepia utilis*
17.	Bhaira	- *Terminalia belerica*
18.	Bheemal	- *Grewia optiva*
19.	Bhentra	- *Juniperous communis*
20.	Burans	- *Rhododendron arboreum*
21.	Chakotra	- *Citrus decumana*
22.	Chanchri	- *Ficus gibbosa*
23.	Charbi	- *Sapium sebiferum*
24.	Cherry	- *Prunus cerasus*
25.	Chhichhri	- *Pleetranthus rugosus*
26.	Chichola	- *Albizzia lebbek*
27.	Chimia	- *Macropanax oreophilom*
28.	Chir	- *Pinus roxburghii*
29.	Chula	- *Prunus armenica*
30.	Daikarn	- *Melia azedarch*
31.	Darwi	- *Cedrela serrata*
32.	Deodar	- *Cedrus deodara*
33.	Dharu	- *Punica sp.*
34.	Dhaura	- *Anogeissus latifolia*
35.	Gadanelli	- *Trema orientalis*
36.	Gadaru	-
37.	Gajla	-
38.	Gald	- *Olea glandulifera*
39.	Gauuta	- *Myrsine semiserrata*
40.	Genthi	- *Boehmeria regulosa*
41.	Ghoda	- *Vitex glabrata*
42.	Gogna	- Saurau'a *nepalensis*
43.	Goi	- *Melisoma dilleniaefolia*
44.	Gonthia	-
45.	Gurial	- *Bauhinia purpurea*
46.	Haldu	- *Adina cardifolia*
47.	Hallyon	-
48.	Harra	- *Terminalia chebula*
49.	Jamun	- *Eugenia jambolana*
50.	Jhau	- *Tamarix gallica*

51. Kachnaar - Bauhinia variegata
52. Kail - Pinus excelsa
53. Kaiphal - Myrica nagi
54. Kakaad - Pistacia integerrima
55. Kangra - Loranthus longiferous
56. Kangu - Flacourtia ramontchi
57. Karmara - Averrhoa carambola
58. Karunda - Carisa spinarum
59. Kathal - Artocarpus integrifolia
60. Kathaman - Eugenia jambolana var. caryophyllifolia
61. Khair - Acacia catechu
62. Khajur - Phoenix sp.
63. Kharik - Celtis australis
64. Kharina -
65. Kheda -
66. Kiamal - Berberis spp.
67. Kingora - Berberis aristata
68. Klinna - Sapium insigne
69. Kubabol - Lucaena leucocephala
70. Kuri - Nyctanthes arbortristis
71. Kusuma - Schleichera trijuga
72. Lahod - Symplocos crataegoides
73. Lani - Suaeda sp.
74. Malta - Citrus aurantium var. Malta
75. Mandar - Acer caesium
76. Mohru - Quercus dilatata
77. Mohua - Bassia latifolia
78. Mola - Pyrus patia
79. Narangi - Citrus aurantium
80. Nashpati - Pyrus sinensis
81. Nimbu - Citrus medica
82. Pangarar - Erytherina indica
83. Papeeta - Carica papaya
84. Peepal - Ficus religiosa
85. Phalsa - Grewia asiatica
86. Phangar -
87. Pharsu - Grewia asiatica
88. Pina - Ehretia acuminata
89. Plaman - Syzygium cerasoides
90. Plum - Prunus cerasifera
91. Ramna - Acacia pinnata
92. Rara - Randia dumetorum
93. Reetha - Sapindous mukrosii
94. Safeda - Eucalyptus hybrid
95. Sal - Shorea robusta
96. Salu -
97. Samlan - Qugenia oojeinensis
98. Sandan - Ooginia dalbergidges
99. Santra - Citrus aurantium var. Santra
100. Seb - Pyrus malus
101. Semal - Bombax ceiba
102. Semla - Bauhinia retusa
103. Shetut - Morus alba
104. Shka - Cornus macrophylla
105. Simali - Zizyphus sativa

106. Surai - *Rosa involucrata*
107. Suru - *Pueraria tuberosa*
108. Thanthra - *Rhamnus virgatus*
109. Tilfera - *Cocculus lourifolus*
110. Timla - *Ficus roxburghii*
111. Tour - *Bauhinia vahlii*
112. Tun - *Cedrela toona*
113. Tung - *Rhus cotinus*
114. Utis - *Alnus nepalensis*

Appendix 4.2 Regression equations used for height and volume computation

	Species	Height	Volume
1.	Burans (*Rhodendrum arboreum*)	3.319529 + 3.525574*G	$-0.0026 + 0.03762^{*}\ G^2H$
2.	Timla (*Ficus roxburghii*)	2.878462 + 3.578325*G	$-0.0026 + 0.0461^{*}\ G^2H$
3.	Banj (*Quercus leucotrichophora*)	2.784689 + 3.879138*G	$-0.0012 + 0.04245^{*}\ G^2H$
4.	Bheemal (*Grewia optira*)	2.972410 + 4.903643*G	$-0.0054 + 0.03642^{*}\ G^2H$
5.	Kharik	2.972410 + 4.903643*G	$-0.0054 + 0.03642^{*}\ G^2H$
6.	Tun (*Cedrela toona*)	3.581754 + 4.036010*G	$-0.0032 + 0.03854^{*}\ G^2H$
7.	Reetha (*Sapinodous mukrosii*)	2.423328 + 4.696997*G	$-0.0018 + 0.0413^{*}\ G^2H$
8.	Paiyan (*Syzygium cerasoides*)	2.062419 + 6.832168*G	$-0.007683 + 0.0547179\ D^2H$
9.	Genthi (*Boehmeria rugulosa*)	− 0.02132 + 8.679112*G	$0.07055 + 0.471211\ D^2H$
10.	Gurial (*Bauhinia purpurea*)	3.124372 + 6.826221*G	$0.07055 + 0.471211\ D^2H$
11.	Khinna (*Sapium insigne*)	2.393816 + 7.235686*G	$-0.007683 + 0.0547179\ D^2H$
12.	Ainyaar (*Pieris ovalifolia*)	1.077553 + 8.419118*G	$0.016615 + 0.47929\ D^2H$
13.	Chir (*Pinus roxburghii*)	− 0.13559 + 11.52437*G	$0.0789 + 0.3047\ D^2H$
14.	Others		$-0.2151 + 3.562^{*}\ D$

Appendix 4.3 Volume table for Sal (site quality III)

Diameter class (Inches)	Timber in round		Smallwood stem branch (ft^3)	Branchwood timber smallwood plus stem smallwood (ft^3)
	Stem (ft^3)	Branch (ft^3)		
Over 4-8	0	0	4.5	4.5
Over 8-12	6	0	7	7
Over 12-16	21	0	8.5	8.5
Over 16-20	43	4.5	14	19.5
Over 20-24	72	9	24	35
Over 24-28	110	14	34.5	52
Over 28-32	157	18.5	45	68.5

Source: Growth and Yield Statistics of Common Indian Timber Species, Vol. II. FRI, Dehradun. Reproduced from Indian Forest Records Vol. XII Part I (1925)

Appendix 4.4 Tables for biomass distribution in different villages

Table 4.3 Distribution of woody biomass in various stratum under different plant species at village Chopra

Stratum	Production (m^3)						Growing Stock (t)	Percent (%)	Total Sustainable Yield ($t\ yr^{-1}$)	Area (ha)	Y (
	Bheemal	Kharik	Gurial	Tun	Misc.	Total					
Agricultural land	85.341	46.753	27.300	165.158	318.803	643.355	428.90	54.12	8.58	20.62	0
Homestead	123.645	51.363		0.786	229.267	405.061	270.04	34.07	5.40		
Village land	13.486	0.457	3.038	39.106	84.305	140.392	93.59	11.81	1.87	1.68	
Total	222.472	98.573	30.338	205.050	632.375	1188.808	792.54	100.00	15.85		
Percent	18.71	8.29	2.55	17.25	53.19						

Table 4.4 Distribution of woody biomass in various stratum under different plant species at village Gadil

Stratum	Production (m^3)					Growing Stock (t)	Percent (%)	Total Sustainable Yield ($t\ yr^{-1}$)	Area (ha)	Yield/ha ($t\ ha^{-1}\ yr^{-1}$)
	Bheemal	Kharik	Banj	Misc.	Total					
Agricultural land	1369.0	388.1		447.1	2204.3	1469.5	85.1	29.4	19.1	1.5
Homestead	62.3	69.5	35.6	218.6	385.9	257.3	14.9	5.1		
Total	1431.3	457.7	35.6	665.7	2590.2	1726.8	100.0	34.5		
Percent	55.3	17.7	1.4	25.7						

Table 4.5 Distribution of woody biomass in various stratum under different plant species at village Bhiatoli

Stratum	Production (m^3)					Growing Stock	Percent	Sustainable Yield	Area	Productivity
	Burans	Banj	Ainyaar	Misc.	Total	(t)	(%)	(t yr^{-1})	(ha)	(t ha^{-1} yr^{-1})
Agricultural land		68.2		766.3	834.6	556.4	16.9	11.1	18.3	0.6
Homestead				335.4	335.4	223.6	6.8	4.5		
Village land	526.1	1536.1	216.3	1494.3	3772.8	2515.2	76.3	50.3	16.5	3.1
Total	526.1	1604.3	216.3	2596.1	4942.8	3295.2	100.0	65.9		
Percent	10.6	32.5	4.4	52.5						

Table 4.6 Distribution of woody biomass in various stratum under different plant species at village Kanda

Stratum	Production (m^3)					Growing Stock	Percent	Total Sustainable Yield	Area	Yield/ha
	Burans	Banj	Ainyaar	Misc.	Total	(t)	(%)	(t yr^{-1})	(ha)	(t ha^{-1} yr^{-1})
Agricultural land		45.8		132.7	178.6	119.1	4.0		15.9	0.3
Homestead				481.0	481.0	320.0	10.9	6.4		
Village land	135.3	738.9	86.4	2790.0	3750.5	2500.3	85.1	50.0	15.5	2.6
Total	135.3	784.7	86.4	3403.7	4410.1	2940.1	100.0	58.8		
Percent	3.1	17.8	2.0	77.3						

Table 4.7 Distribution of woody biomass in various stratum under different plant species at village Kyuri

Stratum	Production (m^3)					Growing Stock (t)	Percent (%)	Total Sustainable Yield ($t\ yr^{-1}$)	Area (ha)	Yield/ha ($t\ ha^{-1}\ yr^{-1}$)
	Burans	Banj	Ainyaar	Misc.	Total					
Agricultural land	7.3			789.8	797.0	531.3	25.2	10.6	118.9	0.1
Homestead		0.1		50.0	50.1	33.4	1.6	0.7		
Village land	74.5	679.8	283.9	1278.7	2317.0	1544.7	73.2	30.9	46.5	0.7
Total	81.8	679.9	283.9	2118.5	3164.1	2109.4	100.0	42.2		
Percent	2.6	21.5	9.0	67.0						

Table 4.8 Distribution of woody biomass in various stratum under different plant species at village Saur

Stratum	Productivity (m^3)								Growing Stock (t)	Percent (%)	Total Sustainable Yield ($t\ yr^{-1}$)	Area (ha)	Yield/ha ($t\ ha^{-1}\ yr^{-1}$)
	Bheemal	Kharik	Timla	Tun	Chir	Genthi	Misc.	Total					
Agricultural land	173.1	422.9	79.3	93.0	149.7	139.3	493.2	1550.5	1033.3	33.6	20.7	62.0	0.3
Homestead	218.4	676.8	5.9	21.9		6.3	576.5	1505.7	1003.8	32.6	20.1		
Village land	89.9	57.0	10.8	20.9	133.7	23.6	1225.3	1561.2	1040.8	33.8	20.8	19.8	1.1
Total	481.4	1156.7	96.0	135.8	283.4	169.2	2295.0	4617.4	3078.3	100.0	61.6		
Percent	10.4	25.1	2.1	2.9	6.1	3.7	49.7		0.0				

Table 4.9 Distribution of woody biomass in various stratum under different plant species at village Siur

Stratum	Production (m^3)					Growing Stock (t)	Percent (%)	Total Sustainable Yield ($t\ yr^{-1}$)	Area (ha)	Yield/ha ($t\ ha^{-1}\ yr^{-1}$)
	Bheemal	Genthi	Paiyan	Misc.	Total					
Agricultural land	148.6	79.3	122.8	479.6	830.3	553.5	66.5	11.1	36.5	0.3
Homestead	0.6	0.6		35.5	36.6	24.4	2.9	0.5		
Village land	2.8	3.3	0.9	373.8	380.9	254.0	30.6	5.1	71.4	0.1
Total	152.0	83.2	123.7	888.9	1247.8	831.9	100.0	16.7		
Percent	12.2	6.7	9.9	71.2						

Table 4.10 Distribution of woody biomass in various stratum under different plant species at village Guad

Stratum	Production (m^3)					Growing Stock (t)	Percent (%)	Total Sustainable Yield ($t\ yr^{-1}$)	Area (ha)	Yield/ha ($t\ ha^{-1}\ yr^{-1}$)
	Bheemal	Kharik	Banj	Misc.	Total					
Agricultural land	106.5	115.6		671.1	893.1	595.4	48.9	11.9	34.2	0.3
Homestead	2.4			4.6	7.0	4.6	0.4	0.1		
Village land	18.1	1.2	298.9	609.4	927.6	618.4	50.8	12.4	69.2	0.2
Total	127.0	116.8	298.9	1285.1	1827.7	1218.5	100.0	24.4		
Percent	6.9	6.4	16.4	70.3		0.0				

Table 4.11 Distribution of woody biomass in various stratum under different plant species at village Tallai

Stratum	Production (m^3)						Growing Stock	Percent	Total Sustainable Yield	Area	Yield/ha
	Bheemal	Timla	Genthi	Khinna	Misc.	Total	(t)	(%)	($t\ yr^{-1}$)	(ha)	($t\ ha^{-1}\ yr^{-1}$)
Agricultural land	97.4	69.4	69.7		564.5	801.1	534.1	30.5	10.7	16.6	0.6
Homestead	2.6	2.7	23.2		23.8	52.3	34.9	2.0	0.7		
Village land	24.9		8.9	286.0	1454.3	1774.1	1182.7	67.5	23.7	23.1	1.0
Total	124.9	72.1	101.8	286.0	2042.6	2627.5	1751.7	100.0	35.1		
Percent	4.8	2.7	3.9	10.9	77.7						

Table 4.12 Distribution of woody biomass in various stratum under different plant species at village Daggar

Stratum	Production (m^3)						Growing Stock	Percent	Total Sustaiable Yield	Area	Yield/ha
	Bheemal	Kharik	Genthi	Khinna	Misc.	Total	(t)	(%)	($t\ yr^{-1}$)	(ha)	($t\ ha^{-1}\ yr^{-1}$)
Agricultural land	428.2	176.1	906.8	286.0	1424.3	3221.4	2147.6	10.7	43.0	40.6	1.1
Homestead					47.8	47.8	31.9	0.2	0.6		
Village land	7.4	14.8	242.3	459.8	25999.6	26723.9	17816.0	89.1	356.3	71.1	5.0
Total	435.7	190.9	1149.0	745.8	27471.7	29993.1	19995.4	100.0	399.9		
Percent	1.5	0.6	3.8	2.5	91.6		0.0				

Table 4.13 Distribution of woody biomass in various stratum under different plant species at village Soni

Stratum	Production (m^3)					Growing Stock	Percent	Total Sustainable Yield	Area	Yield/ha
	Banj	Khinna	Sal	Misc.	Total	(t)	(%)	($t\ yr^{-1}$)	(ha)	($t\ ha^{-1}\ yr^{-1}$)
Agricultural land				957.0	957.0	638.0	4.1	12.8	25.3	0.5
Homestead				18.5	18.5	12.3	0.1	0.2		
Village land	611.6	3178.7	4162.7	14348.6	22301.6	14867.7	95.8	297.4	120.5	2.5
Total	611.6	3178.7	4162.7	15324.1	23277.1	15518.0	100.0	310.4		
Percent	2.6	13.7	17.9	65.8		0.0				

Table 4.14 Distribution of woody biomass in various stratum under different plant species at village Baggar

Stratum	Production (m^3)					Growing Stock	Percent	Total Sustainable Yield	Area	Yield/ha
	Bheemal	Gurial	Banj	Misc.	Total	(t)	(%)	($t\ yr^{-1}$)	(ha)	($t\ ha^{-1}\ yr^{-1}$)
Agricultural land	71.7	36.6	8.2	425.1	541.6	361.1	41.8	7.2	10.0	0.7
Homestead	0.4			0.4	0.8	0.5	0.1	0.0		
Village land	1.6		49.3	702.0	752.9	501.9	58.1	10.0	21.1	0.5
Total	73.7	36.6	57.6	1127.5	1295.3	863.6	100.0	17.3		
Percent	5.7	2.8	4.4	87.0						

Table 4.15 Distribution of woody biomass in various stratum under different plant species at village Kasmoli

Stratum	Production (m^3)						Growing Stock	Percent	Total Sustainable Yield	Area	Yield/ha
	Bheemal	Burans	Banj	Ainyaar	Misc.	Total	(t)	(%)	($t\ yr^{-1}$)	(ha)	($t\ ha^{-1}\ yr^{-1}$)
Agricultural land	389.1	273.8	577.6	1320.2	2118.4	4679.1	3119.4	52.6	62.4	87.8	0.7
Homestead					19.2	19.2	12.8	0.2	0.3		
Village land	7.2	502.7		818.1	2861.6	4189.7	2793.2	47.1	55.9	170.6	0.3
Total	396.3	776.5	577.6	2138.3	4999.3	8888.0	5925.3	100.0	118.6		
Percent	4.5	8.7	6.5	24.1	56.2						

Table 4.16 Woody biomass distribution in various stratum under different plant species at village Bhimalli-malli

Stratum	Production (m^3)					Growing Stock	Percent	Total Sustainable Yield	Area	Yield/ha
	Banj	Kharik & Bheemal	Chir & Kail	Others	Total	(t)	(%)	($t\ yr^{-1}$)	(ha)	($t\ ha^{-1}\ yr^{-1}$)
Agriculture land	1.7	54.25	66.0	4.94	126.89	84.59	7.3	1.70	18.36	0.09
Homestead	-	36.26	-	13.90	50.16	33.44	2.88	0.67	-	-
Forest land	414.3	-	1130.4	15.36	1560.06	1040.04	89.81	20.80	10.36	2.00
Total	416.0	90.51	196.40	34.2	4737.11	1158.07	100.00	23.17		
Percent	23.95	5.210	68.87	1.97						

Table 4.17 Woody biomass distribution in various stratum under different plant species at village Agrora

Stratum	Production (m^3)				Growing Stock (t)	Percent (%)	Total Sustainable Yield ($t\ yr^{-1}$)	Area (ha)	Yield/ha ($t\ ha^{-1}\ yr^{-1}$)
	Kharik & Bheemal	Chir & Kail	Misc.	Total					
Agriculture land	64.43	100.3	48.96	213.69	142.46	13.00	2.85	43.28	0.07
Homestead	36.39	-	35.50	71.89	47.92	4.38	0.96	-	-
Forest land	-	1357.4	-	1357.40	904.94	82.62	18.10	15.12	1.20
Total	100.82	1457.7	84.46	1642.98	1095.32	100.00	21.91		
Percent	6.13	88.72	5.15						

Table 4.18 Woody biomass distribution in various stratum under different plant species at village Bhainsarau

Stratum	Production (m^3)				Growing Stock (t)	Percent (%)	Total Sustainable Yield ($t\ yr^{-1}$)	Area (ha)	Yield/ha ($t\ ha^{-1}\ yr^{-1}$)
	Banj	Chir & Kail	Misc.	Total					
Agriculture land	-	-	12.59	12.59	8.40	0.9	0.20	28.16	0.01
Homestead	-	-	16.38	16.38	10.90	1.29	0.21	-	-
Village forest	264.7	1081.1	-	1345.80	897.20	97.90	17.90	12.66	1.41
Total	264.7	1081.10	28.97	1374.77	916.50	100.00	18.30		
Percent	19.25	78.63	2.10						

Table 4.19 Woody biomass distribution in various stratum under different plant species at village Ghiri

Stratum	Production(m^3)				Growing Stock (t)	Percent (%)	Total Sustainable Yield ($t\ yr^{-1}$)	Area (ha)	Yield/ha ($t\ ha^{-1}\ yr^{-1}$)
	Kharik & Bheemal	Tun	Misc.	Total					
Agriculture land	140.70	18.65	16.24	175.59	117.10	96.2	2.30	25.80	0.09
Homestead	6.40	-	0.56	6.96	4.60	3.80	0.10	-	-
Forest land	-	-	-	-	-	-	-	100.00	-
Total	147.10	18.65	16.80	182.55	121.71	100.00	2.40		
Percent	80.58	10.22	9.20						

Chapter 5
Human exposure to CO and TSP due to bio-fuel combustion

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Chapter 5

HUMAN EXPOSURE TO CO AND TSP DUE TO BIOFUEL COMBUSTION

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5 Human exposure to CO and TSP due to biofuel combustion

5.1 Introduction

It is estimated that in 1990, 72% of India's population was rural based. Economic development has brought modern technology, specially new sources of energy, to these rural communities. But the extent to which these technologies have spread is insignificant. Even in regions where advanced technology is being used for agriculture, energy use in the household sector remains traditional. These communities are characterized by an extensive and almost exclusive use of biofuels in traditional cooking and space heating devices. A significant fraction, 43%, (Natrajan 1985) of the urban population, specially the least income category, also uses such fuels and devices to meet its energy requirements.

Combustion of these fuels occurs in devices that have low thermal efficiencies and high emission factors, and which are largely without flues (Ahuja 1987). Combined with the poor ventilation of the houses in which they are used, the situation has the potential to produce very high concentrations of air pollutants. Adult women in rural India, who constitute about 30% of its rural population, are therefore the group with the highest risk, as they are the ones who do the cooking. Young children (about 12% of the rural population), who are often by their mothers' side when the mothers cook, are also a high risk group.

Though a fairly reliable estimate can be made of the number of people who are likely to be exposed to such smoke, it has still not been widely established whether all of them would be subjected to a similar range of concentrations of pollutants. Only a few studies have been conducted in India which examined this problem; Smith et al. (1983), Patel et al. (1984), Ramakrishna (1988), Menon (1988). These studies were mostly exploratory in nature. They attempted to experiment with different sampling techniques, identifying the characteristic pollutants and determining the effect of various geographical, climatic and socioeconomic factors. These studies confirmed that the levels of Total Suspended Particulates (TSP) and Carbon Monoxide (CO) in rural kitchens can reach exceedingly high values.

It became obvious from these studies that cooking is the major activity that contributes to atmospheric pollution in rural areas. However, the amount of pollutants in other micro-environments (such as living rooms, outdoors, etc.) and the time spent by individuals in these micro-environments have not been measured so far. While it is known that individuals in developed countries spend as much as 90% of their time indoors (Szalai 1972), such data on rural people in developing countries are not available. Cultural factors, traditional practices and climatic conditions would influence the time spent by people in smoky environments. It would therefore be useful to

determine the extent of differences in exposures of populations across regions in the country, owing to these factors.

It was our intention to extend the earlier work by a) measuring the concentrations of CO and TSP in a new geographical setting, b) assessing the daily exposure to TSP and CO, and c) comparing the daily exposure of various groups of the population. The earlier studies in India were all restricted to the plains, stopped at measuring concentrations and focused only on adult women and children. This chapter discusses the distribution of the concentrations of TSP and CO and the factors that affect the concentration and the distribution of daily exposure of four groups within the population. Throughout this chapter concentration means the mass per unit volume and exposure means the product of concentration and time.

5.2 Description of the region under study

The study was conducted in villages in Pauri District of Garhwal Himalaya (Figure 5.1). Garhwal lies in the Central Himalayan region of North India. The highest point in this district is 3098 m while the highest village is at 2480 m. The area has sub temperate to temperate climate and has distinct seasons, unlike most of the areas in the Indian plains. Subsistence agriculture is the main economic activity, with wheat, rice and maize as the major crops. There are also a few cottage industries. Trucks, buses and jeeps are the main modes of transport. The most

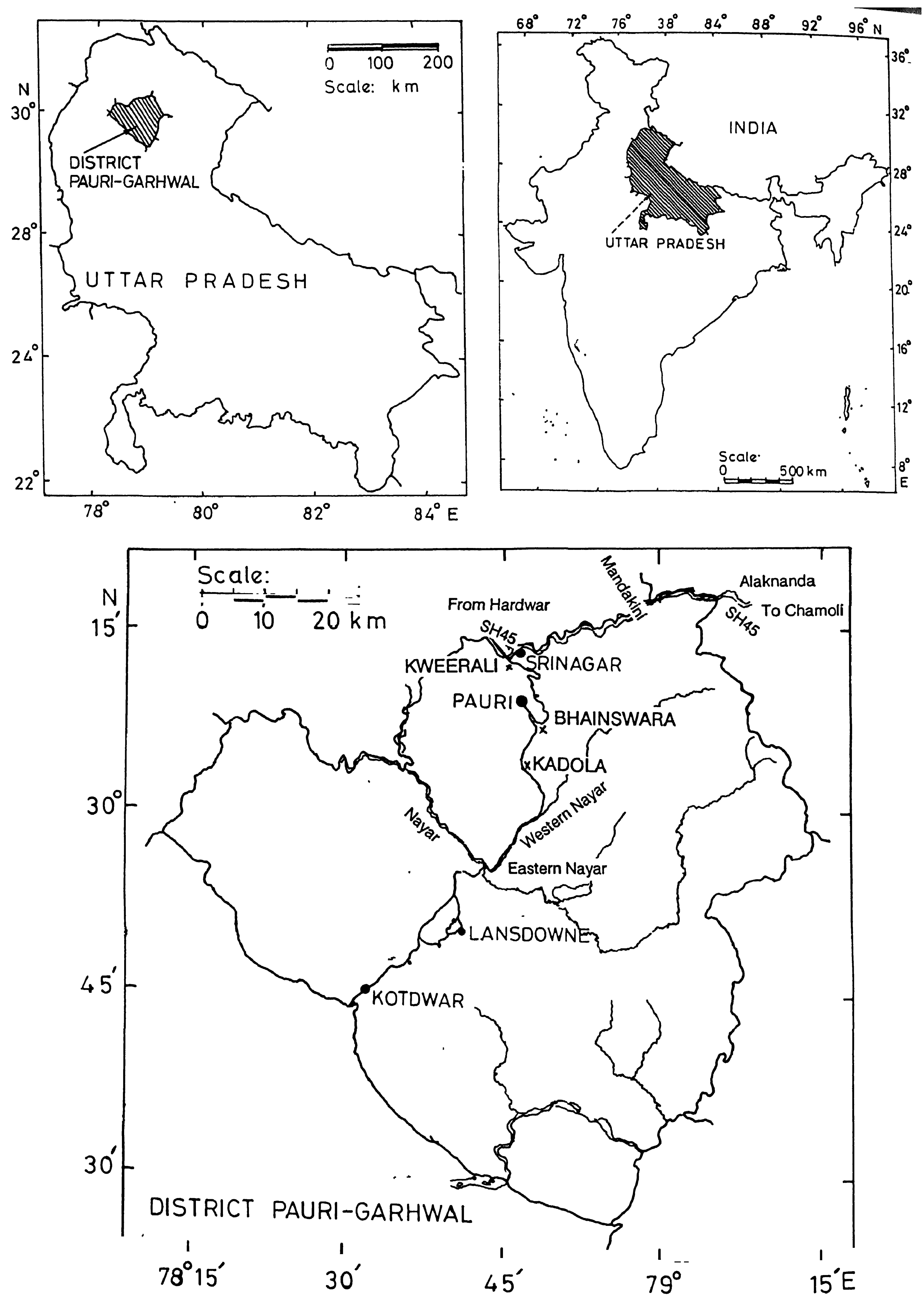


Fig 5.1 Map of the study area

common fuelwood species is 'Chir' Pine (Pinus roxburghii), found from an altitude of 900 m up to 2000 m. Another important species is 'Kharik' (Celtis australis) found between 1300 and 2400 m. Other common trees are 'Banj' Oak (Quercus leucotricophora) and 'Burans' (Rhododendron arboreum) which grow above an altitude of 2000 m. A commonly used shrub, 'Tunga' (Rhus parviflora) is found at altitudes between 900 and 1500 m.

Villages are clustered mainly on the gentle slopes of the ridges on the fluvial terraces. Villages have between 10 to 100 households. The average family size is 6. A typical house has a kitchen and a cowshed forming the groundfloor with two living rooms on the first floor. Houses are constructed with stone, mud and wooden beams. The roofs are made of slate stone. There is no gap between the walls and the roof. Smoke from the kitchen, therefore, flows out only from windows and doors. Combustion of biomass is thus the major source of air pollutants, and most of this occurs indoors. A traditional two port unvented clay stove is used for cooking. These stoves are shaped like a box (about 45 x 60 x 25 cm). The stove is placed on the floor in the kitchen. Crop residues and leaves are burnt in open fields as a mode of waste disposal.

5.3 Study design

The daily integrated individual exposure of four groups of population - adult men, adult women, youth (6-18 years) and children (0-5 years) was assessed. The choice of groups was based on common activity patterns. The assessment involved measuring concentrations of TSP and CO in the more important micro-environments the people of this region spend time in. These are six in number - the kitchen during cooking sessions, the kitchen during non-cooking sessions, the living room, outdoors in vicinity of the village during cooking sessions, outdoors in vicinity of the village during non-cooking sessions and outdoors (fields, etc.), far away from the village. This is not to imply that people of this region cook outdoors but it is anticipated that cooking indoors might release pollutants which leak out into the ambient atmosphere. Micro-environments that were not covered include schools, market places, shops and vehicles. Whenever a reference was made to these latter micro-environments, a suitable surrogate was chosen from the former set of six micro-environments. For example, the outdoor non-cooking micro-environment was substituted for the market place. Our interpretation of the definition of micro-environment ("chunk of air space with homogenous pollutant concentration") differs from the conventional interpretation (Duan 1982, Flachshart 1988). This definition has usually been interpreted to refer only to a physical space. This interpretation does not allow for the fact that human activity might cause pollutant

concentrations to change, even by an order of magnitude, in the same physical space. We show this to be true elsewhere in the chapter. It is therefore not representative to take averages of pollutant concentrations in a given micro-environment that differ widely as a consequence of human activity.

TSP and CO concentrations in these micro-environments were measured using stationary samplers. The only exception was personal sampling of TSP at the time of cooking; for this, the personal sampler was tied around the cook's waist. In all but the cooking micro-environment, there being no known single strong point source of pollutants; stratification is not expected. Therefore, stationary sampling in these micro-environments is a good approximation. Pollutant concentrations were monitored during the three daily cooking sessions (breakfast, lunch and dinner). In the other five micr-oenvironments monitoring was done twice a day - once in the forenoon and once in the afternoon. Monitoring was also repeated over three seasons: monsoon (August 1989-October 1989), winter (November 1989 - March 1990) and summer (April 1990 - July 1990). We planned our visits to the villages to coincide with the peak of each season.

Time budget surveys were carried out to determine how much time each individual spends in each of the six micro-environments. These surveys were conducted twice, once in winter and once in summer.

In a given season, for a given pollutant, the daily integrated individual exposure was computed as follows:

$$E_i = \sum_{j=1}^{6} c_{ij} t_{ij}$$

where

E_i = the daily integrated exposure of the ith individual ($mg\ h\ m^{-3}$ and ppm h for TSP and CO respectively)

C_{ij} = concentration of the pollutant in the jth micro-environment associated with the ith individual ($mg\ m^{-3}$ and ppm for TSP and CO respectively)

t_{ij} = time spent by the ith individual in the jth micro-environment associated with him/her (h)

Here, $\sum_{j=1}^{6} t_{ij} = 24$ h for all i.

After having computed the E_is, the four group averages were computed.

5.3.1 Experimental design

A complete factorial design (Cox 1958) was used to investigate the effects of season, altitude and time of the day. Among the numerous factors that can affect the concentration of pollutants, we found it feasible to consider only these three factors as "controlled" independent variables. The other variables, such as those related to weather and cultural practices, were the "uncontrolled" independent variables of the experiment. Three levels were chosen for each of these factors, as follows: season - monsoon, winter and summer; altitude -

914 m, 1372 m, 1829 m and time of the day - morning (5 to 11 am), mid-day (11 am to 5 pm) and evening (5 to 9 pm). Of these three factors, season and time of the day would be considered as treatment factors and altitude would be a classification factor. The choice of three levels for each factor is justified on the basis that both the slope and curvature of the response surface are more precisely estimated from three equally spaced levels than from four or more equally spaced levels with the same extreme points (Cox 1958). Random ordering of experiments was not feasible owing to logistical problems.

The altitude factor was represented by choosing one village at each of the three altitudes mentioned above. The only criterion used in selecting villages was that they be located far away from the road, to avoid interference from vehicular emissions and resuspended dust from dirt roads. Only a few villages in this district are located along the roads. Therefore this criterion would lead to the selection of representative villages.

5.3.2 Household selection

Samples were selected in two stages. In December 1988, a survey was conducted in the district to get a general picture of the region in terms of parameters such as stove types, fuel usage, house and kitchen characteristics, cooking practices and other possible sources of pollutants. The survey covered 122 households in seven villages. To ensure that variations due to altitude, if

any, would be discernible, a difference in altitude of 458 m between villages was decided upon. From these seven villages, we then chose Bhainswara (1829 m), Kadola (1372 m) and Kweerali (914 m). Two important findings of this survey were: (1) fuel is rarely used for the sole purpose of space heating and (2) crop residues, animal dung and kerosene are rarely used for cooking. Other major findings are presented in **Table 5.1**. From this survey what was immediately apparent to us was that for most of these parameters there is a widespread uniformity, both within a village and between villages. This is not surprising because all villagers have a similar economic status and a narrow range of available resources. Based on this it was decided to choose only typical households for our study. A typical household of this region has these characteristics: fully protected kitchen located downstairs as a part of the house but not connected to any other room. These kitchens, which have an average volume of 20 m^3 (height 1.5 m), are not used for living purposes. (From **Table 5.1** it might appear that there is a significant fraction of households that have a kitchen located upstairs and households that have kitchens connected to other rooms. But this is primarily because of the contribution of the village Naugaon to the average. The situation in this village is unique and cannot be taken as representative.) Another justification for choosing typical households only was the observation in earlier studies (Ramakrishna 1988, Boleij et al. 1988)

Table 5.1 Household and kitchen characteristics

Village	Approx. Altitude (m)	No. of hh	Number of hh surveyed	Total Population	Average family size	Number of hh where the kitchen is located upstairs	Number of hh where the kitchen is also used as living space	Number of hh where the kitchen is attached to another room	Number of kitchens which are partially protected	Number of households with: Only TC	TC and kerosene stove which is used often	TC and kerosene stove which is used rarely	TC and other types of stoves
Kolari	1615	*60	31	*380	6	9	4	12	1	8	5	8	10
Kadola‡	1372	12	12	69	6	0	0	4	0	0	7	0	5
Kandai	1737	12	12	83	7	5	2	6	1	3	3	6	0
Naugaon	1097	18	18	109	6	12	10	5	0	17	0	1	0
Bhainswara‡	1829	*70	18	400	5	5	1	4	0	8	5	5	0
Nakot	762	14	14	57	4	7	5	6	2	1	2	10	1
Kweerali‡	914	17	17	88	5	4	7	3	1	12	0	5	0
Total	-	203	122	1186	-	42	29	40	5	49	22	35	16
Percentage	-	-	-	-	-	35	24	33	4	40	18	29	13

hh - Households, TC - Traditional Chulha (Stove)
‡ - Villages selected for the study

that there is a greater variation of pollutant levels within a household than between households of the same village. A replication factor of four i.e. four households in each village, was decided upon from purely practical considerations, for experiments in the kitchen-cooking micro-environment. At least in two of the selected villages, this roughly corresponds to 25% of the population. For experiments in other micro-environments a replication factor of 2 was chosen. Available data about population parameters were too meagre to arrive at an appropriate sample size. Within a village, households on

a similar elevation were selected. These households were chosen at random from a list of households that agreed to cooperate with the investigators and satisfied the household selection criterion described above. Selecting four households in each of these three villages led to a sample of 70 individuals (17 women, 15 men, 29 youth and 9 children). The response rate was very satisfactory. All the twelve households cooperated in all the three seasons.

5.3.3 Measurements

A personal air sampler, Spectrex PAS3000, was used for TSP monitoring and a portable Ecolyzer model 211 sampler was used for CO monitoring. The TSP sampler has a servo control to adjust for pressure drops. At the time of cooking, the TSP sampler was attached to the waist of the cook, with the cassette (in closed face mode) pinned to the shoulder nearer the stove. The flow rate of the TSP sampler was set to 2 $\underline{l}$ min^{-1}. The CO monitor (which gives instantaneous values) was placed 1 m away from the stove at a height of 60 cm above the floor. (The nose is roughly at that height when a person is squatting on the floor.) The sampling duration was made to coincide with the duration of cooking. CO readings were recorded manually with one-minute intervals.

For the other two indoor micro-environments, both instruments were placed in the center of the room at a height of 91 cm. (The nose is roughly at that height when a person is sitting on a low chair/stool commonly used in

this region.) Sampling duration was set to 1.5 h. For the two outdoor micro-environments in the village these samplers were placed at roughly the center of the village. In all outdoor experiments the samplers were placed at a height of 1.52 m and the sampling duration was set to 4 h. Flow rate of the TSP sampler, for these five micro-environments, was set to 3 $\underline{l}$ min^{-1} if the Spectrex PAS300 sampler was used and to 6 $\underline{l}$ min^{-1} if the Casella AS808 was used.

All samplers were checked and calibrated before and after every experiment. For the CO monitor a 50 ppm span gas was used. The soap bubble technique was used to measure the flow rate of TSP samplers. If the difference between the initial and final flow rates was more than ±10% then that TSP sample was rejected.

Whatman membrane filters of 0.8 µm pore size and 37 mm diameter were used. Filters were desiccated for 24 h with silica gel before weighing them in an electronic balance with an accuracy of 10 µg. This was done in New Delhi. As many filter cassette holders were taken to the field as the number of experiments to be performed, to avoid the risk of the dusty environment contaminating the filters if they were to be transferred from a container to the cassettes in the field. One in every twenty-five filters was used as a field blank. Corrections to the change in mass were made separately for each season.

Other measurements included indoor and outdoor temperature and humidity (using a whirling psychrometer), atmospheric pressure, wind speed and direction, and type, amount and moisture content of the fuel burnt (as applicable in each experiment). Attempts were made to determine the air exchange rates, wherever feasible, by examining CO decay rates.

Special attention was given to designing a protocol for the monitoring of indoor cooking sessions, specially because the participants were not in a position to operate the instruments themselves. This led to a situation where the investigators had to operate many instruments in the confines of the small kitchen where, apart from the cook, there might have been a few more members of the family present. We designed a protocol that ensured a smooth coordination between the investigators and the cook, a minimum disturbance to the normal cooking practices and an efficient measurement of all the variables of interest. This was achieved by first designing a protocol and pre-testing it in March 1989. Mock sessions were conducted in all participating households and also in a village, Dhanawas, near Delhi, giving us an idea of site conditions. From this experience it was decided to modify the original protocol by having two investigators, each with well defined responsibilities. The original single data sheet, which was designed based on categories of variables to be measured, was accordingly split into two

and designed according to the sequence of operations to be carried out by each investigator. The data sheet then served as an efficient check-list as well. Only that information which was needed for a particular experiment was collected. Otherwise, it was observed that both the cook and the investigators felt overburdened and could not concentrate on their primary tasks. Therefore information on basic household parameters and time budgets was gathered on other occasions. Further details of the protocol and data sheet are presented in **Appendix 5.1**.

The mock sessions also exposed the participants to the devices that were to be used, the type of experiments that were to be performed and the role they were expected to play. Once their initial curiosity was satisfied and the awkwardness of the situation got over, their behaviour was more normal when the actual monitoring began in the monsoon season. This, in turn, led to less uncertainty in the data. We feel this to be an important consideration when dealing with rural folk in developing countries.

5.3.4 Time budget survey

Our approach to gathering data on activities--micro-environment--time spent was restricted by the fact that participants could not maintain their own diaries, owing to low literacy rates. Interviewing the participants was then the only way to get the same information. Four questionnaires were designed, one for each of the four groups (adult women, adult men, youth and children). The

four questionnaires differed in the type of activities being considered. The questionnaires were administered twice - once in winter and once in summer. It was considered inadvisable to obtain seasonal information in one attempt, as the memory of people is not reliable in this matter. The questions were carefully framed to obtain only facts and not perceptions.

Yet another approach involved asking the respondent to describe how he or she had spent the day, on the day they were interviewed. This open-ended approach was more successful in accounting for the entire 24 h than the previous approach. However, we could not collect adequate samples from this approach. The first approach gave us an idea of a typical day in that season whereas the second approach yielded the description of a particular day in the season. Data from each approach was then examined to gauge the significance of large deviations, if any, in what was reported to us. Time budget surveys are time consuming (approximately 20 min per person in a season) and therefore we could interview the family members of only those households in which we had measured pollutants earlier.

5.4 Results

The unit response was complete as all households cooperated throughout the programme. There was some item non-response mainly due to inclement weather, instrument malfunction and the practice of some households of not cooking certain meals in certain seasons. Due to constraints of time, it had been our practice to first complete the monitoring of kitchens, during the three cooking sessions, in a village. In the remaining time, efforts were made to complete at least one replication of the factorial design in the other five micro-environments. This explains the reduced sample size in these five micro-environments as compared to the planned sample size. Missing data have not been substituted. All analysis of variance procedures have been carried out using log-transformed dependent variables.

5.4.1 TSP concentration

Summary statistics of TSP concentrations in the six micro-environments are shown in **Table 5.2.** The mean concentration in the indoor cooking micro-environment was at least an order of magnitude more than the mean concentration in the other five micro-environments. From **Table 5.2** it is seen that there is a tendency for each sample statistic to decrease from the first micro-environment to the sixth micro-environment. A two-tailed t-test ($P < 0.005$) showed that the mean of any of the three indoor micro-environments was significantly

different from the mean of any of the three outdoor micro-environments.

Table 5.2 TSP concentrations in the six micro-environments (mg m^{-3})

	Micro-environment					
	1	2	3	4	5	6
Sample size	95	29	21	22	22	3
Minimum	0.55	0.14	0.10	0.00	0.01	0.06
5th percentile	1.03	0.17	0.11	0.00	0.02	-
50th percentile	4.88	0.60	0.43	0.22	0.16	-
95th percentile	14.41	2.93	2.23	1.06	0.76	-
Maximum	19.92	2.95	2.25	1.09	0.77	0.15
Mean	5.64	0.82	0.63	0.26	0.23	0.11
Standard deviation	3.80	0.69	0.57	0.26	0.22	0.05

1 - kitchen during cooking sessions
2 - kitchen during non-cooking sessions
3 - living room
4 - outdoors in the village during cooking sessions
5 - outdoors in the village during non-cooking session
6 - outdoors, far from village

An analysis of variance of the complete factorial design was done on the TSP concentrations in the kitchen-cooking micro-environment. The procedure is summarized in Table 5.3. The effects of the three factors, namely season, altitude and time of day, were highly significant ($P < 0.001$). Together, the three factors and four interaction terms explained 43% of the total variance. Mean concentration was the highest in winter (6.82 mg m^{-3}) followed by summer (5.41 mg m^{-3}) and monsoon

(4.84 mg m^{-3}). Mean concentration was the highest during mid-day (8.26 mg m^{-3}) followed by night (4.94 mg m^{-3}) and morning (4.02 mg m^{-3}). There was no consistent increase or decrease in concentration with an increase in altitude. Analysis of variance of the measurements made in the village Bhainswara showed that 17% of the total variance was attributed to differences between kitchens. The similar figures for Kadola and Kweerali were 22% and 30% respectively.

Table 5.3 Analysis of variance on TSP concentrations in the kitchen-cooking micro-environment

Source of Variation	Sum of Squares	DF	Mean Square	F
Main Effects	3.811	6	.635	12.497 *
Season	.951	2	.475	9.355 *
Altitude	1.077	2	.538	10.592 *
Time of day	1.962	2	.981	19.302 *
2-way Interactions	1.210	12	.101	1.983
Season Altitude	.533	4	.133	2.624
Season Time of day	.033	4	.008	.160
Altitude Time of day	.666	4	.166	3.273
3-way Interactions	.326	8	.041	.802
Season Altitude Time of day	.326	8	.041	.802
Explained	5.347	26	.206	4.046 *
Residual	3.456	68	.051	
Total	8.804	94	.094	

* significant at $P < 0.001$
The dependent variable has been log-transformed

Analysis of variance performed separately for each of the micro-environments labeled 2 to 5 in **Table 5.2** showed only the factor 'season' to have a significant effect ($P < 0.005$). In each micro-environment the winter mean was the highest, followed by the summer and monsoon means.

5.4.2 CO concentration

Summary statistics of CO concentrations in two micro-environments are shown in **Table 5.4**. In the other four micro-environments the concentrations were below the detection limit of the instrument.

Table 5.4 CO concentrations in two micro-environments (ppm)

	Micro-environment 1	Micro-environment 2
Sample size	100	29
Minimum	1	0
5th percentile	4	0
50th percentile	15	2
95th percentile	67	26
Maximum	162	31
Mean	21	4
Standard deviation	22	7

1 - kitchen during cooking sessions
2 - kitchen during non-cooking sessions

An analysis of variance of the complete factorial design was done on the CO concentrations in the kitchen - cooking

micro-environment. The procedure is summarized in **Table 5.5.** Only the effect of the factor 'time of day' is highly significant ($P < 0.001$). Together, the three factors and the four interaction terms explain 40% of the total variance. Mean concentration was the highest in summer (27 ppm), followed by monsoon (20 ppm) and winter (16 ppm). The mid-day mean was the highest (37 ppm), followed by night (19 ppm) and morning (11 ppm). There was no consistent increase or decrease in concentration with an increase in altitude. Analysis of variance of the measurements made in the village Bhainswara showed that 45% of the total variance was attributed to differences between kitchens. The corresponding figure was 20% for both Kadola and Kweerali.

Table 5.5 Analysis of variance on CO concentrations in the kitchen-cooking micro-environment

Source of Variation	Sum of Squares	DF	Mean Square	F
Main Effects	5.130	6	.855	11.327 *
Season	.412	2	.206	2.727
Altitude	.107	2	.053	.706
Time of day	4.576	2	2.288	30.312 *
2-way Interactions	1.366	12	.114	1.508
Season Altitude	.279	4	.070	.925
Season Time of day	.280	4	.070	.926
Altitude Time of day	.717	4	.179	2.374
3-way Interactions	.785	8	.098	1.300
Season Altitude Time of day	.785	8	.098	1.300
Explained	7.281	26	.280	3.710 *
Residual	5.510	73	.075	
Total	12.791	99	.129	

* significant at $P < 0.001$
the dependent variable has been log-transformed.

Analysis of variance of measurements made in the kitchen during non-cooking sessions showed the factors 'season' and 'time of day' to have a significant effect ($P < 0.005$). The mean concentration was the highest in summer (6 ppm), followed by monsoon (4 ppm) and winter (3 ppm). In this micro-environment the forenoon mean (7 ppm) was higher than the afternoon mean (1 ppm).

The above discussion on the distribution of CO concentration relates to the time weighted average in each measurement session. For the kitchen-cooking micro-environment the instantaneous CO concentrations from 100 sessions are summarized in **Table 5.6**. The log-transformed data shows a skewness of -0.15.

Table 5.6 Instantaneous CO concentration during cooking sessions (ppm)

Statistic	Value
Sample size	8904
Minimum	0
5th percentile	1
50th percentile	12
95th percentile	59
Maximum	354
Mean	19
Standard deviation	25

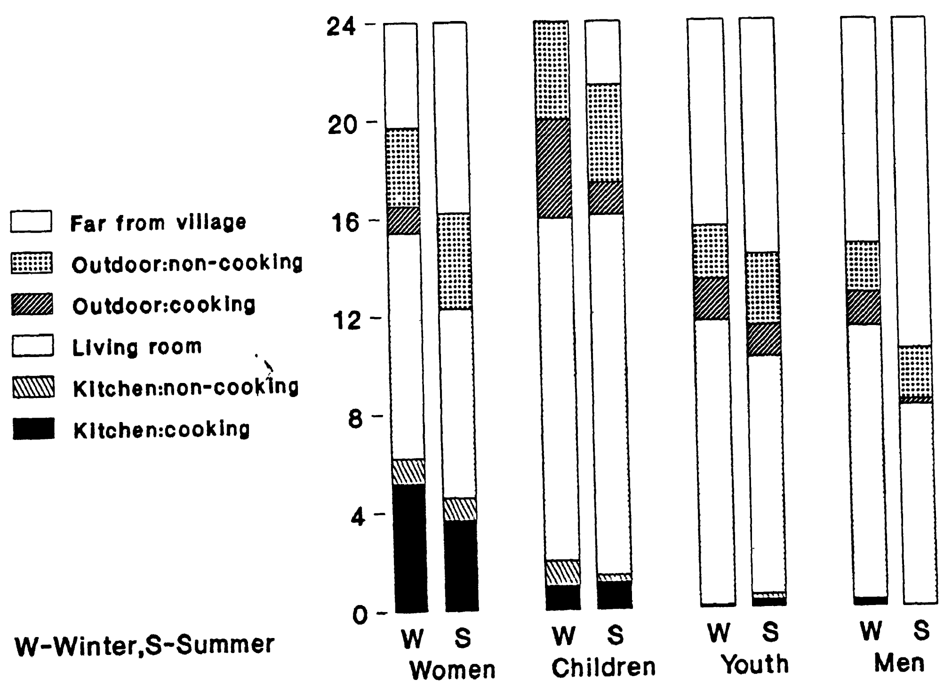
5.4.3 Correlation between TSP and CO

Correlation analysis of the time weighted average of the simultaneously measured TSP and CO concentrations during cooking sessions resulted in a coefficient of 0.66. The coefficient has a two-tailed significance of 0.001.

5.4.4 Time budgets

Figure 5.2 summarizes the results of the survey to study the time spent in a day in the six micro-environments. Adult women spend 64% and 51% of their time indoors during winter and summer respectively. Adult men spend 48% and 34% of their time indoors during winter and summer respectively. Youth spend 49% and 43% of their time indoors during winter and summer respectively. Children spend 67% of their time indoors in both winter and summer.

Fig 5.2 Mean time spent in a day in in the six microenvironments (h)



5.4.5 Daily exposure of adult women due to cooking

The daily exposure to TSP and CO was computed by summing the exposures during the three cooking sessions in each kitchen. These exposures were in turn computed by taking the product of the concentration measured in a session and the duration of that session. Results are summarized in **Table 5.7.**

Table 5.7 Measured daily exposure of women due to cooking

	CO (ppm h)	TSP (mg h m^{-3})
N	36	36
Minimum	23	3.59
Maximum	248	35.43
Mean	69	16.83
Standard deviation	42	8.44

5.4.6 Daily integrated individual exposure to TSP and CO

For four groups of the population the daily integrated individual exposure was determined using the model mentioned earlier in the chapter. The results are summarized in **Table 5.8** and **Table 5.9** for TSP and CO exposures respectively. It is seen that while the daily exposure to TSP is higher in winter than in summer for all the four groups, it is the other way around for CO. Only the two kitchen micro-environments contribute to the daily integrated exposure to CO.

Table 5.8 Mean daily integrated exposure to TSP (mg h m^{-3})

	Adult Women [17]	Children [9]	Youth [29]	Adult Men [15]
Winter	46.61 (16.98)	24.51 (12.70)	18.94 (8.42)	16.83 (7.85)
Summer	27.08 (15.30)	12.87 (5.41)	7.70 (3.16)	5.84 (0.68)

[] - Number of members in the group
() - Standard deviation

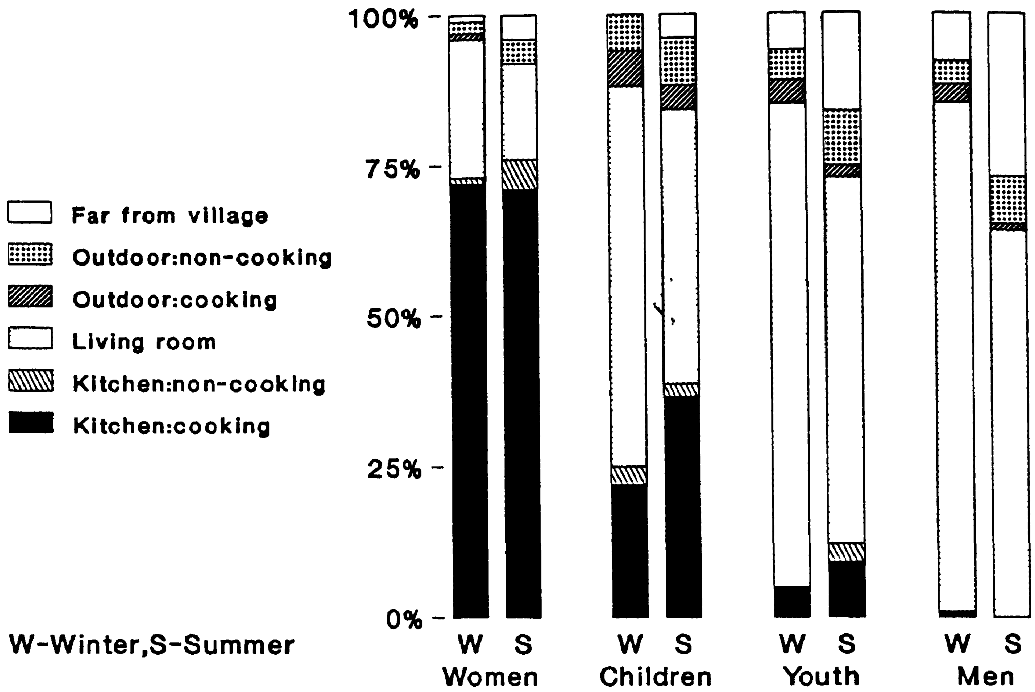
Table 5.9 Mean daily integrated exposure to CO (ppm h)

	Adult Women [17]	Children [9]	Youth [29]	Adult Men [15]
Winter	95 (43)	18 (7)	1 (4)	1 (3)
Summer	125 (118)	38 (26)	6 (12)	0 (0)

[] - Number of members in the group
() - Standard deviation

To study the effect of each micro-environment the percentage contribution of each micro-environment to the daily integrated exposure to TSP was computed. The results are summarized in Figure 5.3. For adult women cooking contributes the most to the daily exposure to TSP. For adult men, youth and children it is the time spent in the living room that contributes most to the daily exposure to TSP. For these three groups it is the greater percentage contribution of the living room in winter that leads to the daily exposure to TSP being higher in winter than in summer. Agricultural activity contributes

Fig 5.3 Contribution of each micro-environment to the daily exposure to TSP



significantly to the daily exposure to TSP for adult men and youth in summer. The long summer vacation enables youth to participate in kitchen chores. This explains why their exposure in the kitchen is higher in summer than in winter.

There are two observations that are contrary to what was anticipated. One, for adult women the daily exposure to TSP in the kitchen during non-cooking sessions is higher in summer than in winter. Second, the daily exposure to TSP due to the kitchen-cooking micro-environment is higher in summer (5.28 mg h m^{-3}) than in winter (5.18 mg h m^{-3}) for children. The latter observation may be explained by the fact that time budgets of children were obtained from their parents and this may have led to some errors.

For all population groups the variation in daily exposure attributable to differences between households and individual differences was found to be insignificant.

Analysis of variance of the daily exposure to TSP showed that season and altitude had a significant effect ($P < 0.001$). But here again, as in the case of concentrations, no consistent trend is seen with increasing altitude.

5.4.7 Relationship between measured and modelled daily exposure

The daily integrated individual exposure discussed in the preceding section has been arrived at using the model mentioned earlier in the chapter.. Though concentrations were actually measured, the time budgets were reported values only. But for one micro-environment, namely the kitchen-cooking micro-environment, the measured time data are available. Using these, the daily exposure of women due to cooking was arrived at and the results are presented in **Table 5.7.**

These results can be compared with the results of the model for the kitchen-cooking micro-environment. For CO the actually measured mean daily exposure of women due to cooking is 69 ppm h, while the modelled mean exposure is 105 ppm h. For TSP the corresponding figures are 16.83 mg h m^{-3} and 27.35 mg h m^{-3} respectively. On an average, the modelled exposure is 1.5 times the measured exposure due to cooking. This is understandable when the

discrepancy between the measured and the reported values of the average time spent in cooking per day are examined. While the former value is 3.3 h the latter value is 4.5 h. However, an overall reduction factor for the modelled value of the daily integrated individual exposure can be arrived at only if we know where individuals are overestimating and where they are underestimating the time they spend.

5.4.8 Fuel usage patterns

Type of fuel used

As mentioned earlier, woody biomass is the primary fuel used in this region. Crop residues and animal dung are rarely used for cooking. In the village Kweerali (914 m), 'Chir' Pine (*Pinus roxburghii*) was used in 37% of the cooking sessions and 'Tunga' (*Rhus parviflora*) was used in 21%. A shrub, Lanterna (*Lanterna Camara*), was used in 12% of the cooking sessions. In the village Kadola (1372 m), 'Tunga' was predominantly used (46%); while 'Chir' Pine was used in only 11% of the cooking sessions. In Bhainswara (1829 m), 'Chir' Pine is the most commonly used fuel (48%); followed by 'Banj' Oak (*Quercus leucotricophora*) (21%). Thus it would appear that the tree species 'Chir' and the shrub species 'Tunga' are commonly used in this region.

A single species was used in 43% of the cooking sessions; while a mix of two species was used in 33%.

Moisture content of the fuel

Moisture content of the fuel (%) was measured using an electrical conductivity meter which had been calibrated appropriately. If a mix of more than one type of fuel was used for cooking then the mass weighted average moisture content was computed. Mean moisture content was found to be 12 (range: 7-34, n = 96)%. Analysis of variance showed that season has a significant ($P < 0.005$) effect on moisture content of fuel. The monsoon, winter and the summer means were 14, 13 and 9% respectively. In this region the gathering and storing of fuelwood begins just after monsoon and continues during the winter months. In summer, the agricultural activities prevent collection of fuelwood. This may explain the discussed seasonal effects.

The average moisture content for 'Tunga', 'Chir' and 'Banj' is 14%, 10% and 11% respectively.

Cooking time

Measuring time spent in cooking has been the easiest and most reliable of all measurements made in our experiments. The only uncertainty associated with this measurement was that the presence of the investigators might have altered the normal practices of the cook. But the effect of this was expected to be same in all instances. The mean time spent in cooking a meal was measured and found to be 66 (range: 16-203, n = 100) min. The seasonal means are 64, 74 and 60 min for monsoon, winter and summer respectively.

The mean time spent in cooking a meal is the same for meals cooked in the morning and evening, i.e., 70 min. Meals prepared at midday have a mean cooking time of 55 min. Analysis of variance showed that, very strangely, neither season nor the time of day factor have a significant effect on the time spent in cooking a meal. This is contrary to our intuition that cooking would last longer in colder seasons. Also, since different types of meals are cooked at different times of the day, this would also lead to significantly different means. We are unable to explain the observed results and only further measurements would help clarify the matter.

Cooking time was found to vary significantly with altitude. But here again our findings are unusual. Cooking done in kitchens at lower altitudes lasted longer than in kitchens at higher altitudes. It was expected that at higher altitudes the lower temperature and atmospheric pressure would cause the duration of cooking sessions to be longer.

Fuel consumption per capita

The mean of the amount of fuel consumed per capita per meal was found to be 0.30 (range: 0.06 to 0.85, n = 96) kg. Variations due to time of the day factor were found to be insignificant. It was expected that amount of fuel consumed would vary depending on the type of food being cooked. Since only one type of food is cooked in a meal; it was expected that the differences in means at

different times of the day would be significant. The results of this study do not support this hypothesis in this region.

Variations in the per capita fuel consumption due to differences between households were found to be between 14 and 25% of the total variation.

Seasonal variations were found to be significant ($P < 0.05$). The seasonal means are 0.33, 0.32 and 0.25 kg for monsoon, winter and summer respectively.

Figure 5.4 shows the relationship between the amount of fuel consumed per capita per meal and the family size. Fuel consumption is least for families with 6-8 members. Beyond this size, fuel consumption increases. However, because of the few samples of large families, these observations are not conclusive.

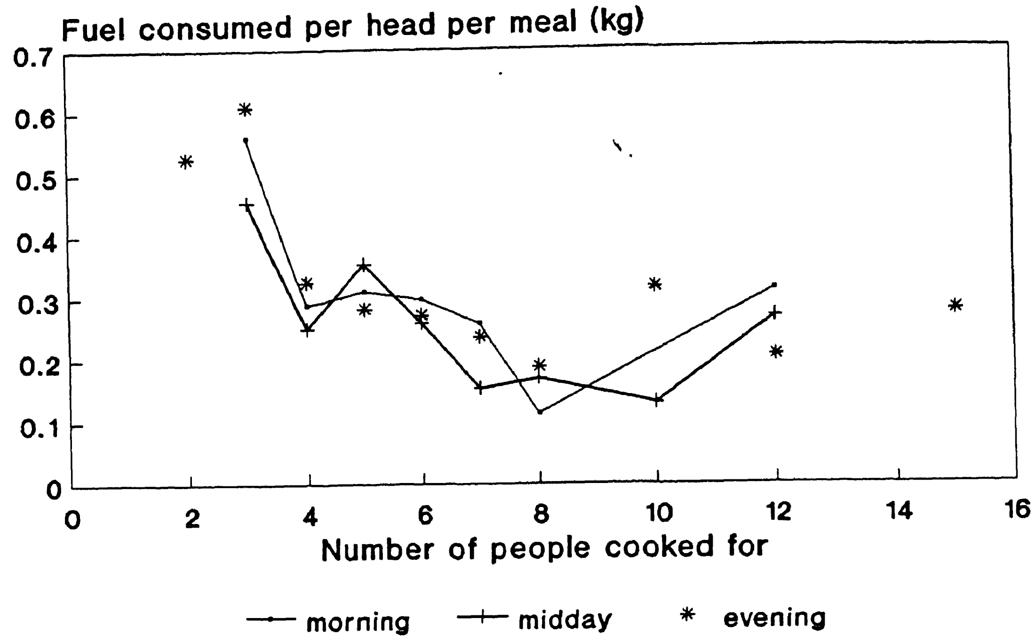
Fuel burnrate

The mean fuel burnrate was found to be 1.49 (range: 0.32 to 4.85, $n = 96$) kg h^{-1}. Variations due to season and time of day were found to be insignificant. Variations due to differences between households contributed only 5-19% of the total variation.

Remark

Fuel usage patterns are uniform across households in a village.

Fig 5.4 Fuel consumption vs family size



5.5 Discussion

The concentrations of TSP and CO measured in this hilly area during cooking sessions are in the same range (TSP: 3-16 mg m^{-3}, CO: 6-51 ppm) as the concentrations measured by others in the Indian plains (Smith et al. 1983, Ramakrishna 1988, Menon 1988). Certain studies have been carried out in Nepal which, like Garhwal, is a hilly region (Reid et al. 1986, Davidson et al. 1986). TSP concentrations as measured in our study are comparable to those measured in Nepal (3-9 mg m^{-3}), but the CO concentrations (40-240 ppm in Nepal) measured by us are less by at least an order of magnitude.

Adult women spend some time in the kitchen during non-cooking hours, preparing for later meals or caring for the

children. Mean concentration in this micro-environment was found to be significantly high for both TSP and CO. This may be due to poor ventilation, which in turn leads to low air exchange rates.

In the living room and outdoors, CO concentrations were found to be below the detection limit of our instruments. This suggests that CO has its source only in the combustion of biofuels and that CO which escapes the kitchen is quickly diluted. TSP concentrations in the living room were, however, non-zero. This may be due to infiltration of air from the kitchen and outdoors and re-suspension of dust. Indoor concentrations of TSP were higher than outdoor concentrations.

The variation in concentrations due to differences between households was much less than that due to differences within households. This indicates that we were successful in selecting similar households. Since these households are typical of the region it is expected that concentrations are uniformly distributed across all households in the study area.

Concentrations of TSP and CO were strongly influenced by the time of the day when the measurements were made. Concentrations measured during mid-day were significantly higher than the evening and morning concentrations.

Seasonal differences were more significant for TSP concentrations than for CO concentrations. The pattern

they followed was also different. TSP concentrations in each micro-environment were highest in winter followed by summer and monsoon. CO concentrations were highest in summer followed by monsoon and winter. Our results are contrary to intuition, which suggests that concentrations would be the highest in cooler seasons (due to ventilation conditions and the longer duration of cooking) and in evening cooking sessions (again due to the longer duration of cooking). This chapter only describes the patterns of concentrations and exposures; it is beyond its scope to provide valid explanations for these patterns. However, future research may wish to test the hypothesis that in this range of altitude, the inside and the outside temperature and the difference between the two influences the concentration of pollutants. Of course, quality of fuel may be another influencing factor.

The results of this study are inconclusive regarding the effect of altitude on concentrations. Though for TSP concentrations there was a significant effect of altitude, we did not observe a consistent increase or decrease in concentrations with increasing altitude. Several species of fuelwood are available at any given altitude. There is also a difference in available species at different altitudes. Therefore, an experiment where the type of fuelwood is controlled may be more successful in determining the effect of altitude.

The time budget survey indicates that women and children are the only groups that stay indoors longer than they stay outdoors. But even for these two groups the time spent indoors is significantly less than the time spent indoors by their counterparts in more developed societies. In an agricultural society, such as the one which has been studied, such patterns are to be expected.

However, for all groups of the population, the indoor micro-environments contribute more to the daily integrated exposure than the outdoor micro-environments. While for women it is cooking that contributes most to the daily exposure, for other groups it is the time spent in the living room which contributes the most.

The daily integrated exposures to TSP and CO follow the same patterns as their respective concentration patterns with respect to season and altitude. In any village, the variation in daily exposure due to individual differences within a group was only a small fraction of the total variance. We had defined exposure as the product of concentration and time. As discussed earlier the variation in concentration due to household differences is small. The responses to the time budget survey were highly uniform across individuals of a group. This would then explain the uniformity in daily exposure across individuals of a group. Whether the time-activity patterns are in fact uniform, or whether it is only the response to the survey questionnaire that is uniform, remains uncertain.

A tendency was observed for individuals to overestimate the time spent in cooking. This led to the estimated daily exposure due to cooking to be higher than the measured value by roughly a factor of 1.5. Better estimates of daily exposure would require either the use of 24 hour personal sampling (which demands a great deal of co-operation from participants and infrastructure not readily available in villages) or detailed field observations of activity patterns (which demand a lot of efforts from the investigators).

In designing this study we were guided by past studies in the matter of measurement of concentrations. For the first time a daily integrated exposure model has been used for rural areas in developing countries. The uncertainties in time budget surveys as discussed above are therefore of greater concern than the uncertainties associated with concentration measurements. However, for the first time some estimates are available for the daily exposure to TSP and CO, showing again that adult women (over 19 years) and children (0-5 years) are at a high risk. It is now acknowledged that daily exposure is a better indicator of health risk than concentration (Smith 1988). Yet, the uniformity in daily exposure across households and individuals would suggest that unless intervention can create a sub-population with significantly lower exposures, it will not be possible to establish the effects on health.

5.6 Directions for future research

5.6.1 Measurement of concentrations

1. Research needs to be done on pollutants for which existing data is not adequate, e.g. - Respirable Suspended Particulate matter (RSP), Polynucleic Aromatic Hydrocarbons (PAH), Volatile Organic Compounds (VOC), Oxides of Nitrogen (NO_x), etc.

2. Future studies should attempt personal sampling of Carbon Monoxide.

3. Concerted efforts must be made to develop cheaper and easier sampling techniques, since this is a problem largely confined to the developing world. The instruments available currently had been designed and developed for industrial and occupational situations. These might be too sophisticated and not appropriate to the levels of pollutants encountered in rural kitchens. They further demand a lot of infrastructural facilities in the field (such as electricity for charging batteries, large quantities of span gas for calibration, etc.) as well as a high degree of cooperation from the cooks. These are hard to come by in poor rural communities. While designing new techniques it must also be appreciated that the confines of the small kitchen and the cultural habits of the people do place restrictions on the type of instruments and techniques that can be effectively employed.

5.6.2 Exposure assessment

1. Personal sampling over 24 h would provide the most reliable estimate. There is one drawback to this: In these communities most of the population groups perform heavy labor of some sort. It would therefore be difficult for them to carry around personal samplers, however mini at sized, all day long. Only a few individuals may cooperate satisfactorily.

2. As an alternative to the above point, future studies could attempt more refined and detailed time budget surveys. It would be preferable if investigators made observations and measurements in the field rather than rely on respondents to fill up questionnaires. In very large studies it would be advisable to first get acquainted with the daily and seasonal 'micro-environment--activity--time' patterns of the region. This would help in designing appropriate pollution monitoring strategies.

5.6.3 Study design

1. There is a need for a standard protocol which should be followed by researchers across regions. Only this would lead to meaningful comparisons of data from different regions.

2. Results from our study and those by others indicate that it is both more effective and appropriate to make many repeated (during a day, across seasons, etc.) measurements in a few households rather than make few measurements in many households.

5.6.4 Alternative energy sources

1. More studies are required to establish the effectiveness of improved stoves in reducing exposures. Preferably exposure should be assessed before and after the installation of the improved stove in a household, with at least a time lapse of at least six months.

2. Many villages in this region are moving towards new sources of energy (kerosene, LPG, electricity). There is also a migration of people from villages to towns. The trade-off in risks associated with various sources of energy needs to be examined.

5.6.5 Health

It has been found that smoke accumulated in the kitchen or other rooms of the house poses a direct threat to the health of the people. The incidence of Acute Respiratory Infections in children and diseases like chronic bronchitis, asthma, suphysema, lung cancer and corpulmonale in women can be attributed to the fact that women and small children are the ones who spend most of the time in ill-ventilated kitchens. Moreover the fuel used for cooking i.e. biomass emits a lot of smoke when burned. Therefore, intervention studies need to be done but before carrying them out baseline surveys should be done to identify places where intervention is needed most.

5.6.6 General

Exposure assessment is very expensive. Therefore, it becomes all the more necessary to understand the distribution and variability in fuel usage patterns, housing characteristics, weather, climate, socio-cultural factors, health indicators, etc. before designing and exposure measurement program. Many studies have made the mistake of studying these factors while simultaneously assessing exposure. Often, the results have not been conclusive. This could be avoided in the future by first conducting surveys in the field which gather information on the above factors.

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Appendix 5.1 Protocol to be followed while monitoring indoor cooking sessions

1. Both investigators reach kitchen at least an hour early.

2. Both fill up section A of their respective data sheets. Investigator 1 handles data sheet Part I and Investigator 2 handles data sheet Part II.

3. Fix up weather instruments, CO monitor, etc. at prescribed locations in the prescribed manner.

   Investigator 1 handles --> weighing balance, PAS

   Investigator 2 handles --> weather instruments, CO monitor

4. Investigator 1 makes observations on stoves, people, cook etc. Investigator 2 makes observations on initial weather parameters.

5. Investigator 1 asks cook to set aside wood to be used in current session, weighs the wood and passes it on to the cook. Fills up item No. 11 of Part 2. If the amount of wood set aside initially is insufficient, more wood is to be supplied after weighing it and noting it down in the same place.

6. Investigator 1 attaches PAS on cook and removes end-plugs from cassettes. Cassette to be attached on right/left shoulder depending upon which side of stove cook is sitting on.

7. Investigator 1 switches on PAS on receiving a signal from Investigator 2 who notes the time.

8. Investigator 2 switches on CO monitor, time to be noted.

9. One minute later, the cook is asked to light fire. Investigator 2 notes time when fire was lit and when cooking began.

10. While cooking is going on, Investigator 1 fills up items 13 to 19 of Part I and Investigator 2 takes down the CO readings. Investigator 1 may use the start/stop facility of the stop watch to keep track of how long the cook actually stays in the kitchen.

11. On being told that the cooking has ended, Investigator 1 notes the time and weighs the leftover fuel.

12. Investigator 1 removes wood from the kitchen. Investigator 2 continues to take CO readings for 20 minutes at one-minute intervals, or until the display indicates zero continuously for 3 minutes, whichever is earlier.

13. Investigator 1 returns to switch off PAS and the time. PAS can be switched off when it is certain that the cook will not re-enter the kitchen.

14. Investigator 1 takes final readings of weather instruments.

15. Investigators fill up remaining portions of their respective data sheets.

Chapter 6
Strategies for mitigating environmental stress

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Chapter 6

STRATEGIES FOR MITIGATING ENVIRONMENTAL STRESS

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6 Strategies for mitigating environmental stress

6.1 Background

One of the main objectives of the project was to choose selected locations in the Garhwal region and develop model projects that may reverse the existing trend of environmental degradation, using technologies which would lead to rapid afforestation and harnessing of renewable sources of energy. Initially a micro-hydel station was to be set up for studying and managing the benefits from it. The benefits from it were to include irrigation of an arid mountain site where a plantation project was started by the Garhwal University and also provide electricity to the villages, particularly for lighting.

Accordingly, a feasibility study was carried out for establishing a micro-hydel project near Agrora in the Irgad micro-watershed to provide water to a plantation maintained by the Garhwal University. **Table 6.1** summarizes the data on discharge. The discharge was found to be lower than the one assumed in the feasibility study. A detailed estimate of costs was prepared and corresponding benefits assessed. **Table 6.2** shows the findings of this feasibility exercise in brief. Considering the costs and the limited benefits it was decided to concentrate more on other activities in the project.

A survey of villages in the Irgad micro-watershed enabled us to identify following needs of that area.

i) drinking water,

ii) improvements in fuel supply situation,

iii) improvements in fuel use efficiency,

iv) appropriate soil and water conservation package, and

v) educational programmes to improve environmental awareness.

In addition, we also decided to identify new sites for micro-hydel projects in the surveyed micro-watersheds. In the following sections, we describe our experiences in developing energy projects in the area and the implications of these experiences at the level of district planning.

Table 6.1 Discharge of Irgad stream

Month	Discharge ($ft^3 s^{-1}$)
December 1988	5.6
February 1989	6.3
March 1989	5.2
May 2 1989	0.5
May 8 1989	0.5

Table 6.2 Assessment of costs and benefits of the multipurpose micro-hydel project at Agrora

Phase	Activity	Investment (Rs)	Benefits
I	Construction of dam, installation of turbo pumps, construction of reservoir at nursery	3,64,929	Irrigation of nursery
II	Construction of reservoir near Pali village Laying the pipe line, along the hill slopes	1,17,420	a) Drinking & irrigation water to Pali village (8 families) (22 cattle population) b) Irrigation of part of university plantations
III	Installation of 5 kW for alternator electrification	50,470	Electrification of plantation site and street lights in Pali village
IV	Laying of pipe line and construction of reservoir at Kolri village	1,75,100	Drinking water to Kolri village (70-90) families 150 cattle population and irrigation for 100 ha land
V	Laying the pipe line along university site	1,15,360	Irrigation of entire plantation

6.2 Dissemination of improved chulhas

The household sector in India accounts for half the total energy consumption in the country. In rural areas, particularly in the hills, the share of household sector in total energy consumption is about 90%. Whereas in the hills about 80-90% of energy is consumed in households. The main energy consuming activities are cooking, water heating, space heating, preparation of fodder, etc. Primarily, twigs and logs are used for meeting the thermal energy needs.

The supply situation for biofuels in the hills is varied, however as can be seen from earlier chapters, the environment is under stress. The area also is characterized by low availability of kerosene, LPG and low purchasing power of the people. The response to such a situation has been to increase the \supply of biofuels through afforestation programmes and to promote improved cooking stoves. We observed during the survey that unvented metal improved stoves were promoted and used partially, whereas improved mudstoves with flues were not disseminated. Hence, the Tata Energy Research Institute initiated the demonstration and dissemination of Improved Chulhas (IC) with flues to examine their potential for conservation of energy and reduction in emissions. The main objectives of the programme were:

1) to train villagers to install improved chulhas,
2) to improve the kitchen environment by eliminating smoke from the kitchen, and
3) to conserve energy.

6.2.1 Description of cooking energy system

We selected villages Kadola, Bhainswara and Kweerali for implementation of improved chulhas as we had measured human exposures to pollutants in these three villages. The villages Kadola, Bhainswara and Kweerali are located at the height of 1372 m, 1829 m and 924 m respectively. The number of households are 16, 80 and 17 respectively.

We found that cooking energy systems in these villages were similar. The main components of a cooking energy

system in a house are: 1) Chulha, 2) Fuel, 3) Cooking vessels, 4) Kitchen, 5) Food items, 6) Cooking practices and other uses.

Chulha

From a survey we found that the following types of chulhas are commonly used:

1) traditional, two port, mud chulha
2) U-shaped, one port, tin, portable chulha (Angithi)

The 'Jalagam' (Watershed Management) authorities also distributed the 'Priyagini' portable chulha which villagers use for water heating, outside the kitchen. The two port traditional chulha is made by village women.

Fuels

The major fuels of Bhainswara village are twigs and logs of 'Banj', 'Burans', 'Chir' and 'Tunga' shrubs. Villagers burn dung-cakes for creating smoke in their cow-sheds, to drive away harmful insects. In Kadola, 'Tunga' (twig) is the main fuel. Villagers also use 'Chir', 'Kharik' and other local species as fuel.

Table 6.3 Daily per capita energy consumption

Village	No. of hh	Twigs (kg)	Logs (kg)	Kerosene (l)	Electricity (units)
Kadola	16	0.53	.03	.03	0.2
Bhainswara	80	0.52	.11	.027	0.2

Source: Survey by TERI
hh: households

In the survey we also observed that fuel wood is collected in the months of September, October, December, January and June. Women cover about 1-3 km in search of fuelwood. The average time spent daily in collecting fuelwood was found to be 4 h and 3 h in Bhainswara and Kadola respectively.

Cooking vessels

Flat and round bottomed; brass, aluminium and iron (kadai) vessels are commonly used. In some households pressure cookers are also used.

Kitchen

Kitchens have an average volume of 20 m^3 (height = 1.5 m). Usually, kitchens are located on the ground floor, as a part of the house, but not connected to any other room. The chulha is commonly found in one corner of the kitchen. It is fixed to the floor by mud.

Food items

Roti and rice are the major food items.

Table 6.4 Consumption of food items

Food item	Consumption (kg per capita per day)
Roti	0.30
Rice	0.20
Vegetable	0.10
Pulses	0.05
Others	0.15

Source: Survey by TERI

Cooking practices and other uses

In Garhwal, a villager cooks three times in summer - morning, noon and evening. In winter they cook only two times - morning and evening.

Table 6.5 Time spent in cooking

	Summer (h)	Winter (h)
Morning		
Tea	0.3	0.4
Food	1.0	1.3
Noon		
Tea	0.2	0.2
Food	1.2	-
Evening		
Tea	0.4	0.7
Food	1.1	1.5

Source: Survey by TERI

But we also observed that in periods of intensive agricultural activity more food is cooked and cooking sessions last longer probably in the month of April-May, July-August.

6.2.2 Pilot survey and chulha selection

A survey was conducted in the month of March, 1990 to examine the demand for improved chulhas. We found that about 90% of villagers in Bhainswara and 100% in Kadola and Kweerali desired the IC. Villagers were ready to spend about Rs. 15 on each chulha and showed interest in being trained.

The selection criterion for IC design were:

1) Chulha to be made of mud and sand, because these are locally available.
2) Adaptable design and size; depending on household need.
3) Smoke removal potential.

The two port 'Uttra' chulha developed by Swarajay Mandal, Almora was selected for installation in these villages. TERI staff was trained at IIT, New Delhi to construct this chulha. The cost per stove was about Rs. 90.

6.2.3 Dissemination, monitoring and evaluation of improved chulhas

The strategy adopted was:

i) Village meetings to discuss firewood-forestry (energy) problems.

ii) Discussion with villagers about chulha.

iii) Creation of awareness through booklets, chulha diagrams, etc.

iv) Programme logistics decided with villagers.

v) Demonstration of the improved chulha and monitoring them along with traditional stoves.

vi) Analyzing the above data to identify problems.

vii) A large scale dissemination programme after acceptance of new technology.

In September 1990, TERI organized a village meeting in Bhainswara and decided that the chulha programme would be held in October 1990 for 10 days. During the programme

villagers suggested twenty households for chulha programme and desired that demonstration be organized in every corner of the village. After the discussion session we selected 5 families and visited them. We informed them about the programme and from the third day to the eighth day, we built five Uttra chulhas in the village.

After fifteen days we began the second phase programme in the central part of Bhainswara and trained three local people. At the same time we installed five more Uttra chulhas. We faced the following difficulties:

1) Distance between houses was considerable
2) Variation in the location of kitchen
3) No ventilation in kitchen
4) Roof of kitchen made of stone
5) Bend was necessary in chimney
6) Width of the wall of houses was quite significant

Method of construction

A mixture of about clay (60 kg), sand (10-20 kg), wheat husk (3-4 kg) and cow-dung (about 8-10 kg) was prepared and kneaded after adding water. The mixture was allowed to ferment for 2-3 days.

As per requirements, water was added to the prepared clay mixture to obtain a consistency so that the stove would not disintegrate after construction. A rectangular wooden hollow frame was made and filled with clay mixture. Planks were removed after 24 hours. The outlines of the

fire box, port holes and chimney hole were made on the top of block. The fire box and port holes were made by scooping out mud from the block. To ensure proper contact between the flue gases and second port, a baffle was provided in the centre of the port hole. The chimney was fitted into a hole dug in the top corner of the stove.

We were able to install 16 chulhas in Bhainswara, 15 in Kadola, 12 m in Kweerali, one in Ghiri and one in Chindalu village. A newly made chulha dried in about 2 to 4 days, only after which the users were encouraged to use it.

To understand the maintenance and various operational problems one trainee was selected based on her interest in chulha work. TERI staff visited the village once a week to ensure proper usage and advice the cook on any problems. The following parameters of the chulha were checked:

1) Tunnel
2) The baffle, for reduction in its heights and changes in its shape
3) Whether chimney was cleaned
4) Whether chulha was coated regularly or not

By visiting villages we found that households changed the chulha port diameter according to their needs.

A detailed evaluation of the chulha performance in the village was found desirable. The aim of evaluation was to determine the thermal efficiency under field condition and users reactions to the improved chulha.

After the survey of the users we were able to identify following constraints in further promotion of this technology, even though 85% of stoves were in use at the time of survey.

1. Due to bends and other problems 30% families reported problems with chimneys and smoke removal.
2. 25% of the families did not perceive any fuel saving and in fact reported higher consumption.

In order to examine the variation in the performance of due to: (1) change in design (diameter) and (2) the measurement method as well as the level of skill in construction of stove, we conducted the thermal efficiency test on 4 improved and 4 traditional chulhas. The experiment was conducted by using the test procedure prescribed by the Department of Non-conventional Energy Sources.

The improved stoves had a maximum efficiency of 19.0% and a minimum of 17.0%. But the traditional chulhas had a maximum efficiency of 14.5% and a minimum of 9.6%. It was observed that water in the second port, boiled on improved chulhas, but did not boil on traditional ones, while using the same amount of fuel and time.

The current designs of improved stoves with flues appear to have limited application in the hills due to the kitchen structures. However, more work would be needed to assess the ability of improved chulhas to remove smoke and conserve energy in the hill areas.

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6.3 Biomass development

6.3.1 Impacts of deforestation

Causes of deforestation are many but its consequences, in terms of run-off and soil loss, depend upon the nature of land use after the loss of forest cover. An extensive literature search led to the estimates of soil loss from different land uses under Indian conditions (Table 6.6).

Table 6.6 Soil loss from different land uses

S.No.	Land use	Annual soil loss ($t\ ha^{-1}$)
1.	Forest	
	a) Dense well-managed	Nil - 0.069
	b) Ill-managed (denuded lands)	20.0-60.0
2.	Grasslands	Nil - 2.0
3.	Agricultural land	
	a) Without soil conservation	1.1 - 84.0
	b) With soil conservation (varying from simple agronomic practices to engineering measures)	0.9 - 14.9
4.	Fallow lands	1.3 - 155.9

We used this data to estimate soil loss from Irgad micro-watershed.

Erosion intensity-wise distribution for various land uses of the total 4934 ha area of Irgad micro-watershed is given in **Table 6.7** (adopted from Plan for Centre of Excellence at Irgad of Watershed Management Project, Pauri).

Table 6.7 Erosion intensity-wise area distribution for each land use in the Irgad micro-watershed

Land use	Erosion intensity-wise area (ha)			Total area (ha)
	Slight	Moderate	Severe	
Forest	322	354	Nil	676(13.7%)
Agriculture	23	2760	199	2982(60.5%)
Blank	0	118	1158	1276(25.8%)
Total	345(7.0%)	3232(65.5%)	1357(27.5%)	4934(100%)

If for slight and severe erosion the lower and upper limits of soil loss are used respectively, and for moderate erosion the average value is used from Table 6.7, the soil loss from from Irgad micro-watershed will be as in Table 6.8.

Table 6.8 Soil loss for different land uses for Irgad micro-watershed

Land use	Annual soil loss (t)
Forest	159.3 (0.04%)
Agriculture	131143.3 (40.86%)
Blank	189653.6 (58.10%)
Total	320956.2 (100%)

Average annual soil loss will be 65 t ha^{-1}.

Based on the above indicative calculation, it can be concluded that the major contribution to total soil loss comes from agricultural and fallow lands. In the following section, a tentative methodology to compare the run-off and soil loss from a presently fallow land and from a fallow land after taking suitable soil and water conservation measures is discussed.

A survey of hills in Pauri Garhwal was conducted and the type of erosion was found to differ according to the gradients of the slopes. They are mainly of three types:

a) Highly eroded with exposed gravels, pebbles, boulders etc., with too little soil component.

b) Mildly eroded with little soil and exposed gravels.

c) Not very much eroded land with reasonable amount of soil.

The slopes in category `c' are the best sites for plantations. Careful follow up would allow survival of plantations in `b' type. Type `a' is worst for any plantation as lack of nutrients and water holding capacity would create highly adverse conditions for any vegetation to grow.

On the other side of Pauri there is a continuous valley from Pauri (high hills) to Kotdwar (plains). This valley receives continuous deposits, part of this deposit moves down-hill.

There is need to conduct studies relating to soil erosion intensity and its quantification. This can be done by setting up silt observation posts (SOP) at various altitudes and various types of slopes. SOP includes stage level recorder (to monitor water-flow), rain gauge (to monitor rainfall) and silt sampler (to collect silt samples for further analysis) as major components. A concrete-cement structure is constructed to control the flow and pass the water stream through stage level recorder. Size and shape of this structure is decided with the help of intensity of expected flow, based on slope and rainfall.

Broadly SOPs should be placed in following types of locations:

i) a treated catchment where plantation has been done

ii) an untreated catchment with naked hill slope with almost nil vegetation except some local grass

iii) badly exposed/erode slope

iv) in the valley which is receiving continuous siltation.

6.3.2 Plantation at Kadola village

Afforestation of 10 acres of village community land at Kadola, was taken up in July 1990. Kadola is about 16 km from Pauri on the Pauri-Kotdwar road. The site was situated in a 500 ft deep V-shaped valley. The plantation site was on the western aspect, running north to south; having very steep slope at both the ends. At the right end (north aspect), it had a good 'Chir-pine' stock mixed with _Ficus_ ('Toon', 'Sandan', 'Shesham' and 'Berberis' shrubs. The left corner was subjected to severe soil erosion because of steep slope. South to south-western aspects were completely devoid of tree species except for some _Exphorbia_ and _Berberis_ shrubs. A rivulet flows along the full length of site, which provides sufficient water for irrigation around the year. The entire site was earlier protected with a fencing which proved to be ineffective.

A major portion of the site could be classified as a problem-site and unfit for tree-plantation. A strategy

was developed for phased plantations of suitable species, coupled with soil working technologies. On the site, about 10,000 plants were to be planted in total, but in 1990 it was decided to plant only 2,000 plants. In this year, the plantation target was intentionally kept low, not only to observe the performance of selected species, but also to encourage the villagers to take care and perpetuate the plantation on their own. Moreover, it was planned to generate a nursery stock of 8 to 10,000 plants on our own, for which a nursery was prepared on a 57′ x 15′ plot.

The entire nursery area was carved in eleven beds of 1 m-1.25 m width and 15′-17′ length, seven of which were sunken and four were raised beds. The nursery had a capacity to hold about 10,000-11,000 plants. As the project was time constrained, it was decided to generate 2500 plants for the following year's plantation. In the nursery, 1300 poly-bags of Acacia mollisima, 400 of Melia azedarach, 500 of Celtis australis and 200 of Leucaena leucocephala were sown. Besides these we had 450 plants each of Quercus serrata and Melia azedarach which could not be planted in the rainy season of 1990 and were kept for beating-up operation. Seeds, initially procured from Forest Department (Silviculture), Ranikhet, did not germinate appreciably. In the next occasion, seeds were brought from Dehradun for second sowing, of-course a late one. Although seeds germinated very well, but very young

plants could not withstand the severe cold and chilling frost, as a result we had only 1197 plants surviving of the 2400 poly-bags sown, by mid-May 1991. We also had more than 1000 plants of _Acacia mearnssi_ growing very well in three beds. Some seeds are still generating, specially those of _Acacia mearnsii_ and _Melia azedarach_. The local beliefs of unsuccessful winter plantations and beating-up, supported by literature, were not found to be valid, as our 1.5 year old plantation stock was performing well in the field. We had beaten-up 500 plants of 1.5 year old stock, which had shown encouraging results.

Two persons were engaged for the protection and maintenance of the nursery as well as planted stock. Besides executing this work, they also helped in the chulha dissemination programme.

To make this plantation a success on the degraded site, suitability and site-amelioration properties were the main criteria for the selection of species, instead of production of timber, fodder, etc. _Pinus roxburghii_, _Melia azedarach_, _Cedrela toona_, _Acacia mearnsii_ and _Quercus serrata_ were selected and 400, 900, 200, 400 and 100 plants, respectively were planted in the rainy season, i.e. July 1990. In May 1991, it was observed that 51.14 per cent stock was growing well. Mortality was chiefly observed on steep slopes at the right end, which hardly had any soil layer and also at the left end, which was exposed to excessive erosion.

The establishment of nursery and the first phase of plantation costed about Rs 12,000 besides generating employment for one full- and one part-time Field Assistant (essentially local unemployed youth).

Overall, the status of the nursery and plantation is satisfactory. Good cooperation from local people along with encouraging results are expected in the near future. This activity should be continued to learn more about the process of improvement of land and also to study the dynamics of local management in biomass production.

6.4 Identification of sites for micro-hydel projects

6.4.1 Approach

The detailed feasibility report for the micro-hydel site brought out the pitfalls in the earlier approach for proposing a micro-hydel site without having the actual discharge data for the lean season. For further investigations we adopted a methodology of identifying potential sites on the basis of analysis topographical maps for water flow and drops. A survey of these sites together with an end-use planning approach is used to recommend schemes for detailed feasibility studies. This methodology is applied in the surveyed micro-watersheds.

6.4.2 Micro-hydel projects

Irgad micro-watershed

Micro- and mini-hydel power potential for generating electricity and lifting water were assessed from topographical maps of the Irgad micro-watershed. The possible schemes which can totally generate nearly 1000 kW of power were identified. These are shown on a map of the area (**Figure 6.1**). End-uses for the electricity and the water were investigated. Detailed feasibility report for the first of three stages at Agrora has already been prepared in January 1989. The other two stages were surveyed on the Irgad.

The second stage utilizes a discharge of about 20 cusecs and a drop of 300 ft in the bed level. It can develop about 400 kW which can be fed into the local grid. The third stage utilizes a discharge of about 30 cusecs and a drop of 300 ft to develop about 600 kW. The power from the 3rd stage can be used to electrify more than 10 villages west of Jwalpa Devi which are not on the UPSEB's 5-year plan for rural electrification. Several check dams may have to be built at various locations to increase the minimum flow of water. These will also act as a soil conservation measures and the water can be used for local agricultural purposes too. It is recommended that a detailed feasibility study of the second and third stages be carried out.

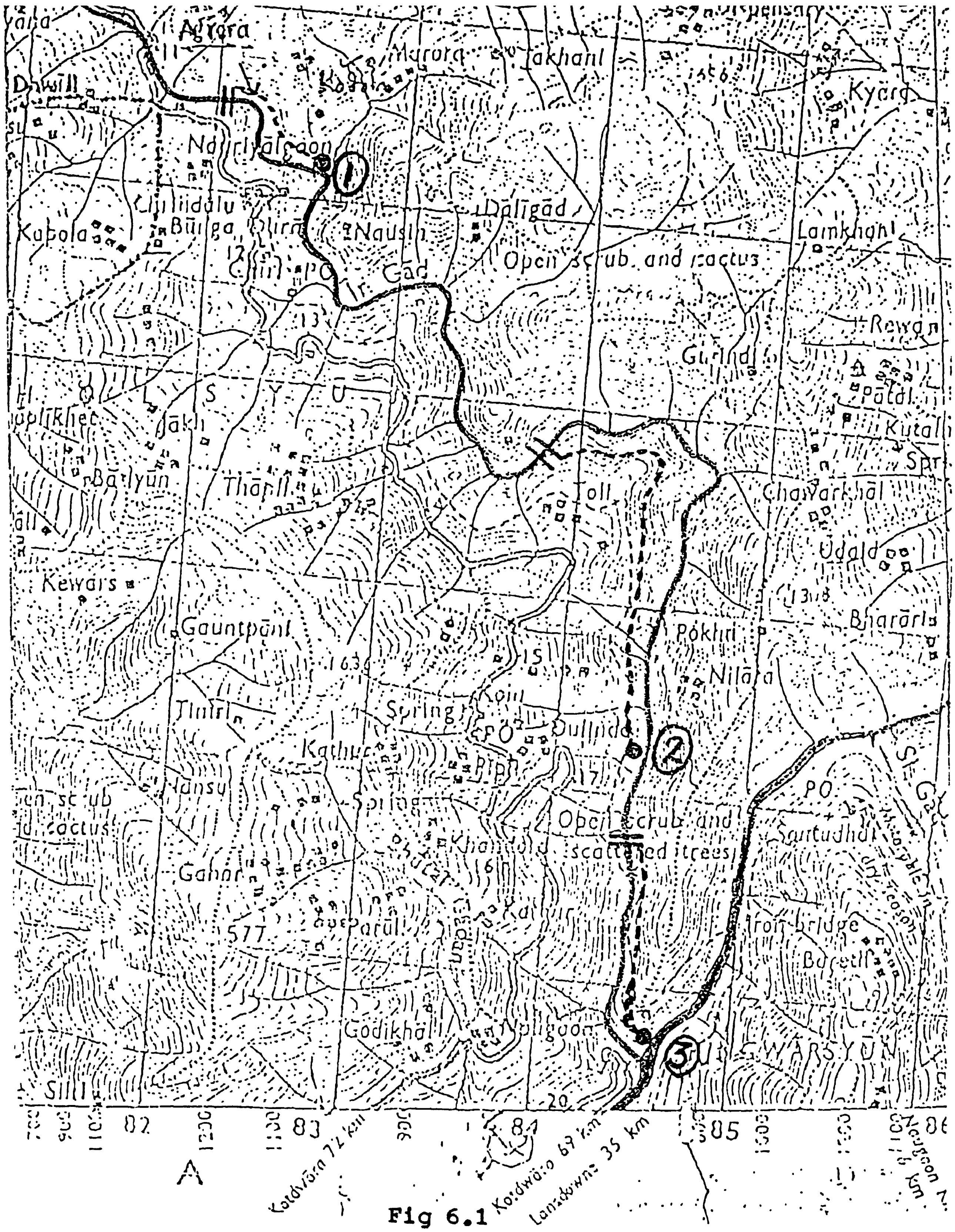

Fig 6.1

SMALL-HYDRO POWER DEVELOPMENT ON IRGAD

STAGE	DROP (ft)	FLOW (cusecs)	POWER (kW)
1.	50	6	20
2.	300	20	400
3.	300	30	600

Stream — Dam or Weir

Head Race — Power House

Chandrabhaga sub-watershed

Micro- and mini-hydel power potential were assessed by studying the 1:50,000 topographical map of the sub-watershed (Survey of India sheet no. 53 - J/8) which contains contours at intervals of 20 m. Two schemes have been identified which can generate nearly 550 kW of power. These are shown on an enlarged portion of the map of the watershed in **Figure 6.2.**

The diversion wier of the first stage can be located nearly 1 km upstream of Haud village on the Chandrabhaga Nadi. The water is then to be taken along the right bank of the stream by a power channel and dropped through a penstock to the power house sited nearly 0.5 km downstream of Haud village. This stage would utilize a discharge of about 20 cusecs and a drop of 60 m (200 ft) to generate about 250 kW.

The second stage would tap the water of the same stream about 0.5 km north of Gujrara village. The water would again be carried by a power channel along the right bank up to a point about 0.5 km roughly south-west of Dhunga village where a penstock would drop the water to the power house. The water from the power house would flow back into the Chandrabhaga Nadi itself. This stage would utilize a discharge of about 25 cusecs and a drop of 60 m (200 ft) to generate around 300 kW.

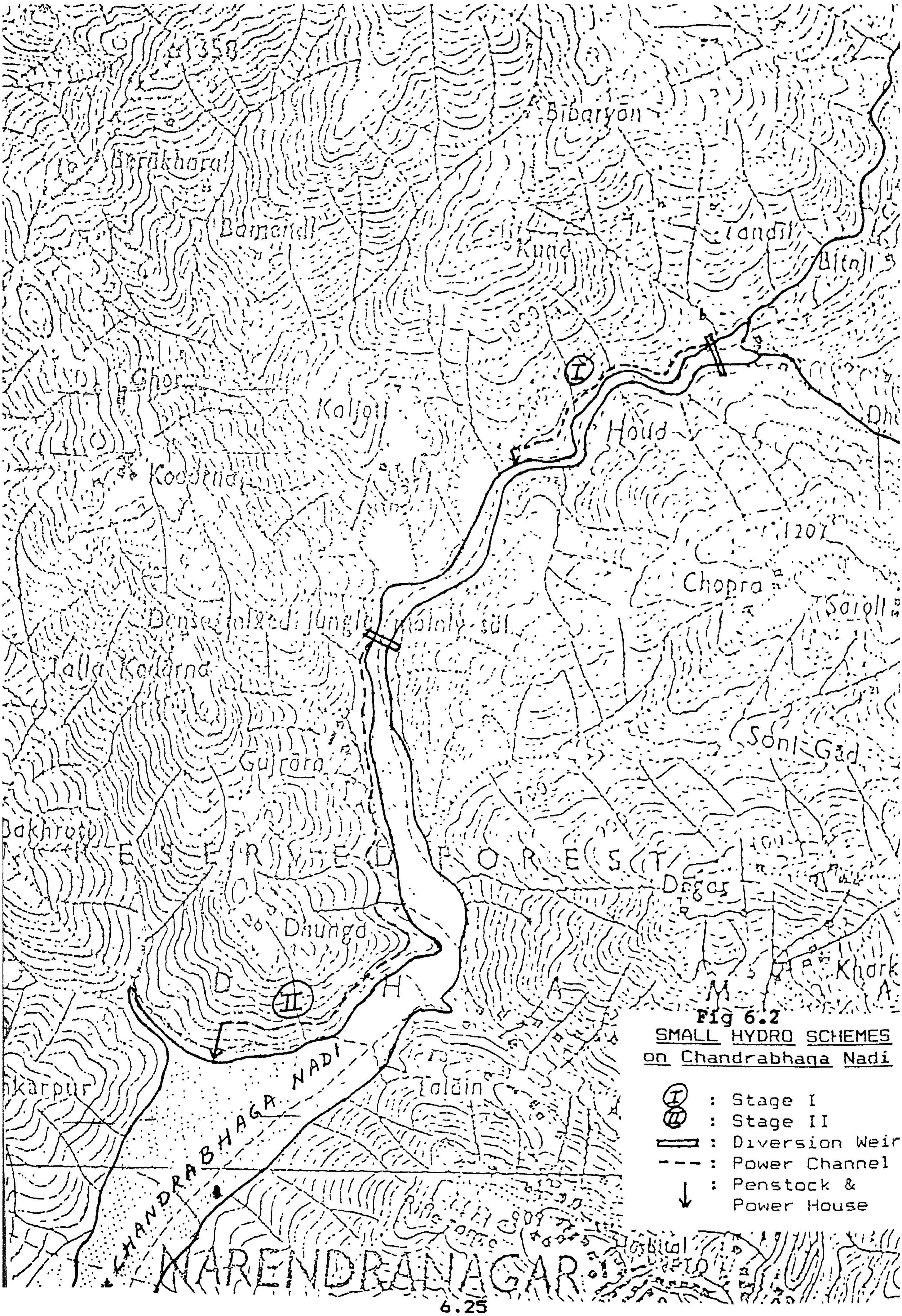

Fig 6.2
SMALL HYDRO SCHEMES on Chandrabhaga Nadi

Sur Gad micro-watershed

Micro and mini hydel potential of the Sur Gad have been assessed by studying the 1: 50,000 topographical map of the micro-watershed (Survey of India sheet no 53 - N/3) which shows contour lines at intervals of 40 m. The hydel potential of the Sur Gad can be harnessed in three stages which, together, can generate about 900 kW. The three schemes are indicated on an enlarged portion of the map in which the schemes are located (**Figure 6.3**).

The first stage is to be on a stretch of 1 km along the Sur Gad, roughly south-west of Tarag village. This stage would utilize a discharge of about 8 cusecs and a drop of 160 m (520 ft) to generate around 250 kW. Since the drop in bed level is fairly steep, a direct penstock can be used instead of a power channel. Either the direct penstock or the power channel could run along the right bank of the stream. The tailrace water will be put back into the stream after power generation.

The intake of the second stage is to be located a few hundred metres downstream of the Stage I power house. This stage would utilize a discharge of about 10 cusecs and a drop of 120 m (390 ft) to generate another 250 kW. Here also, the right bank of the stream is ideal for either the power channel or a direct penstock arrangement till the power house, located near Kalhu village.

The third stage would tap the waters of the Sur Gad roughly 1.5 km before it joins the river Mandakini. This stage would utilize about 20 cusecs of water and a drop of 100 m (325 ft) to generate around 400 kW. The power channel is to follow the contour on the left bank of the Sur Gad till the village Silli Chatti, where a penstock would drop the water to a power house located on the left bank of the Mandakini. The tailrace water could then be let out into the river Mandakini.

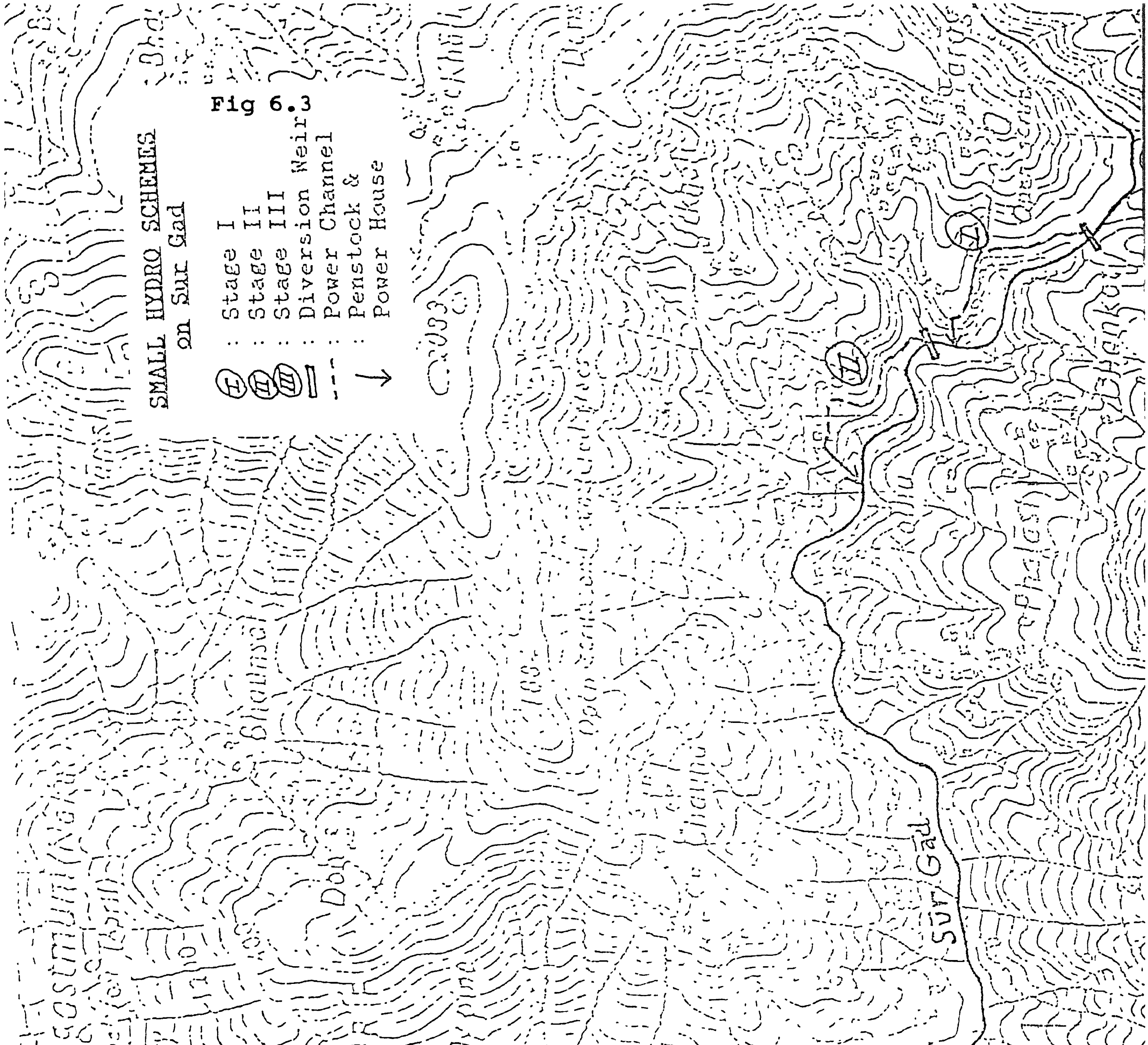
Fig 6.3
SMALL HYDRO SCHEMES
on Sur Gad
I : Stage I
II : Stage II
III : Stage III
: Diversion Weir
: Power Channel
: Penstock &
Power House
Sur Gad

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